AUGMENTED EVALUATION TEAM FINAL REPORT

Emergency and Backup Power Supplies at Department of Energy Facilities

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ABSTRACT

This report documents the results of the Defense Programs (DP) Augmented Evaluation Team (AET) review of emergency and backup power supplies (i.e., generator, uninterruptible power supply, and battery systems) at DP facilities. The review was conducted in response to concerns expressed by former Secretary of Energy James D. Watkins over the number of incidents where backup power sources failed to provide electrical power during tests or actual demands. The AET conducted a series of on-site reviews for the purpose of understanding the design, operation, maintenance, and safety significance of emergency and backup power (E&BP) supplies.

The AET found that the quality of programs related to maintenance of backup power systems varies greatly among the sites visited, and often among facilities at the same site. No major safety issues were identified. However, there are areas where the AET believes the reliability of emergency and backup power systems can and should be improved. Recommendations for improving the performance of E&BP systems are provided in this report. The report also discusses progress made by Management and Operating (M&O) contractors to improve the reliability of backup sources used in safety significant applications.

One area that requires further attention is the analysis and understanding of the safety implications of backup power equipment. This understanding is needed for proper graded-approach implementation of Department of Energy (DOE) Orders, and to help ensure that equipment important to the safety of DOE workers, the public, and the environment is identified, classified, recognized, and treated as such by designers, users, and maintainers. Another area considered important for improving E&BP system performance is the assignment of overall ownership responsibility and authority for ensuring that E&BP equipment performs adequately and that reliability and availability are maintained at acceptable levels.

As a result of the AET review, a Backup Power Working Group (BPWG) was formed to provide a forum for effective communication on a continuing basis among DOE Headquarters, Operations Office, Area Office, Site Office, and M&O Contractor personnel responsible for the design, operation, and maintenance of E&BP equipment. The BPWG's objectives include operating experience feedback (lessons learned), coordination of training efforts, and promoting the use of applicable industry standards and good engineering practices.

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ACRONYM LIST

AC	Alternating Current
AET	Augmented Evaluation Team
ASME	American Society of Mechanical Engineers
ATS	Automatic Transfer Switch
BNL	Brookhaven National Laboratory
BPWG	Backup Power Working Group
CFL	Consequence-of-Failure Levels
CFR	Code of Federal Regulations
DC	Direct Current
DOE	Department of Energy
DP	Defense Programs
DP-62	Office of Engineering and Operations Support
DP-9	Office of Self-Assessment
E&BP	Emergency and Backup Power
EDG	Emergency Diesel Generator
ES&H	Environment, Safety and Health
FMEA	Failure Modes and Effects Analyses
GDC	General Design Criteria
KVA	Kilovolt-Ampere
HVAC	Heating, Ventilation, and Air Conditioning
IEEE	Institute of Electrical and Electronics Engineers
JTA	Job Task Analysis
LANL	Los Alamos National Laboratory
LCO	Limiting Conditions for Operation
LLNL	Lawrence Livermore National Laboratory
M&O	Management and Operating
OJT	On-the-Job Training
NFPA	National Fire Protection Association
NRC	Nuclear Regulatory Commission

NTS	Nevada Test Site
ORPS	Occurrence Reporting and Processing System
OSHA	Occupational Safety and Health Administration
PHA	Process Hazard Analysis
PM	Preventive Maintenance
QA	Quality Assurance
RF	Rocky Flats Site
RL	Richland Site
SAIC	Science Applications International Corporation
SAR	Safety Analysis Report
SIL	Safety Information Letter
SNL	Sandia National Laboratory
SR	Savannah River Site
SSC	Systems, Structures, and Components
TSR	Technical Safety Requirement
UPS	Uninterruptible Power Supply

**UNITED STATES DEPARTMENT OF ENERGY
DEFENSE PROGRAMS
OFFICE OF SELF-ASSESSMENT
AUGMENTED EVALUATION TEAM FINAL REPORT
EMERGENCY AND BACKUP POWER SUPPLIES AT DOE FACILITIES**

1.0 EXECUTIVE SUMMARY

Background

In October 1991, in response to concerns expressed by former Secretary of Energy James D. Watkins regarding the number of incidents where emergency and back-up power supplies failed to provide electrical power during tests or actual demands, the Defense Programs (DP) Office of Self-Assessment (DP-9) was directed to dispatch an Augmented Evaluation Team (AET) to the Richland (RL), Rocky Flats (RF), and Savannah River (SR) sites to evaluate the reliability and availability of emergency diesel generators (EDGs). The review focused on EDGs because there were more reported failures of EDGs than other backup power equipment. The results of the review are documented in Department of Energy (DOE) report No. DOE/DP-0098T "Augmented Evaluation Team Interim Report - Emergency Diesel Generator Reliability at Department of Energy Facilities," dated April 1992. The AET found that problems with EDG starting batteries were the dominant contributor to EDG failures, and recommended that the review be expanded to include batteries used in other backup power applications such as uninterruptible power supplies (UPSs). An expanded AET review was authorized by DP management, and the AET subsequently visited a second group of sites consisting of Pantex, Los Alamos National Laboratory (LANL), Y-12 at Oak Ridge, the Nevada Test Site (NTS), and a return visit to SR to obtain information on UPS and battery systems, and supplemental information on EDGs. This report provides the combined results of the initial AET review of EDG system reliability and the subsequent AET review which also included UPS and battery systems. The results of a joint appraisal of emergency power systems at Lawrence Livermore National Laboratory (LLNL) by the San Francisco Operations Office and DP-9, and a DP-9 review of electrical distribution system events and proposed upgrades at Sandia National Laboratory (SNL), are also factored into this report.

Scope and Review Methodology

The purpose of the AET review was to obtain a clear and factual understanding of the conditions and circumstances surrounding the performance of Emergency and Backup Power (E&BP) supplies. The AET site reviews concentrated on E&BP equipment installed at facilities with substantial nuclear safety hazards, or whose failure appeared likely to jeopardize the safety of personnel or the DOE mission. Objectives of the AET review were to promote an awareness of good engineering practices for E&BP equipment, and to provide recommendations, where necessary, to enhance E&BP system performance and reliability.

The AET assessed the safety significance of E&BP supply applications and the consequences of failures. The AET reviewed Safety Analysis Reports (SARs) to identify design basis requirements for E&BP equipment and assumptions regarding the reliability and availability of E&BP supplies. The AET investigated the root cause(s) and safety significance of failures, inspected E&BP equipment installations and material condition, and reviewed surveillance testing and preventive maintenance programs, procedures, and activities. Data extracted from test and maintenance records and facility operating logs were evaluated to assess equipment performance. The AET interviewed contractor personnel who are directly involved in day-to-day operation, maintenance, and engineering support of E&BP systems. Occurrence Reporting and Processing System (ORPS) data were reviewed to supplement information obtained from the on-site reviews. The findings and conclusions from each of the site reviews were analyzed to assess site-specific and generic safety implications. The more significant findings and conclusions, and the AET's recommendations are summarized below.

1.1 Findings & Conclusions

The following findings are generic to more than one site, but are often not applicable to all sites that participated in the review.

1. At the sites visited, there are in excess of a thousand backup power supplies (i.e., diesel generators, uninterruptible power supplies, and batteries), approximately one third of which provide backup power to equipment that appears to be important to safety (e.g., criticality alarm systems, radiation monitoring equipment, confinement system ventilation exhaust fans, emergency lighting, security systems, and fire alarms).
2. With the exception of some DOE reactor facilities, there are significant differences between EDGs at DOE facilities and EDGs at commercial nuclear power reactors. The EDG installations at DOE facilities are, in general, much smaller and less complex. These designs typically result in easier starts, and are less prone to failure after start. Differences exist in preventive maintenance and surveillance practices because of the smaller and simpler EDG designs. Therefore, it is not always appropriate to apply Nuclear Regulatory Commission (NRC) criteria for EDGs used in the commercial nuclear power industry to EDGs at DOE facilities.
3. The AET observed varying degrees of understanding and application of good engineering practices for operation and maintenance of E&BP equipment. The AET found areas of technical expertise and program excellence at some sites that could benefit other sites. The AET found many examples of similar equipment types and functions where shared information such as design features, procedures, maintenance practices, and lessons learned from operating experience would be useful to personnel responsible for E&BP system design, operation, and maintenance, and could lead to increased E&BP supply reliability. However, there is little communication among DOE sites concerning E&BP systems.

4. The review of load dispatch center logs showed that site distribution system power losses affecting one or more facilities are not uncommon. The loss of normal power to a given facility that challenges the facility E&BP system is clearly a credible occurrence and should be expected. Common causes for loss of normal facility power are inclement weather (rain, snow, sleet, high winds, and lightning), large birds, and personnel error, often involving movement of heavy equipment (e.g., cranes and trenching/drilling rigs). The most common cause for loss of normal power is lightning.
5. Common perceptions among facility personnel are that (1) a complete loss of electrical power will not result in adverse safety consequences, and (2) that the impact (costs and delays) on DOE programs caused by E&BP supply failures is a larger concern than the potential safety consequences to workers, the public, or the environment. However, there was no documentation available to substantiate these perceptions. The safety implications of E&BP supplies at DOE facilities and their contributions to overall risk reduction are not well analyzed or understood.
6. There is little documentation or analysis concerning the safety significance of E&BP supplies. The SAR analyses typically assume high reliability and availability of electric power. The analyses are often outdated and do not address the potential worst-case consequences that could be realistically expected if E&BP supplies fail to function as designed. Worst-case scenarios involving a complete loss of electrical power and an accident (such as fire or unplanned release of toxic or radioactive materials) are not formally analyzed to demonstrate that either the scenarios are not credible (i.e., are extremely low-probability events), or that the consequences are acceptable. The safety significance of E&BP supplies needs to be fully understood so that those supplies important to safety are identified, classified, recognized, and treated as such by designers, users, and maintainers.
7. Failure modes and effects analyses (FMEAs) for electrical systems seldom analyze all credible component failures such as E&BP supplies and automatic transfer switches. There are few applications that use redundant E&BP supplies or that have a diverse alternate source. Redundant E&BP equipment that is provided is typically treated as being independent, even though the redundancy is often compromised by common dependencies and is susceptible to single failures.
8. The reliability of E&BP supplies should improve through the implementation of DOE Orders and ongoing programs to improve SARs, technical safety requirements (TSRs), configuration management, and procedures. However, improvements are to be implemented using a graded approach based on the safety significance of specific E&BP supply applications. The AET believes that the safety significance of E&BP supplies needs to be better understood to ensure effective graded approach implementation of DOE Orders.

9. The AET found a general lack of proper configuration management at most sites as evidenced by failure to maintain adequate E&BP system information such as accurate up-to-date drawings and records of loads assigned to buses and power sources.
10. Using the limited amount of data available concerning EDG responses to tests and actual demands, it appears that EDG reliability is often near or above 90 percent. However, accurate determinations of E&BP system reliability can not be made without substantial improvements in the programs for collection, analysis, and trending of data relating to system failures, down-time, and performance. The areas needing improvements include data quality, quantity, and documentation. Implementation of DOE Order 4330.4A, "Maintenance Management Program," should result in improved monitoring, data collection, performance analysis, maintenance, and reliability of E&BP equipment. Some DOE sites have made significant progress toward implementation of this Order.
11. Contractor maintenance organizations often have not assigned overall responsibility and authority to specific individuals for ensuring that E&BP supplies perform adequately, and that reliability and availability are maintained at acceptable levels. Maintenance, testing, and repair of E&BP supplies is often performed by various independent sub-organizations. The lack of clear lines of authority and responsibility for maintenance activities has affected E&BP system performance.
12. The most successful maintenance programs for E&BP system equipment were found where a clear commitment from site upper management exists in terms of policy/direction and allocation of resources. The AET found many examples of failure of facility management to support maintenance and surveillance activities for E&BP equipment, including (1) not allowing maintenance organizations to schedule maintenance activities for fear of interfering with facility operations, and (2) altering the E&BP system configuration prior to testing to "reduce the impact" on facility operations (a common example is stripping facility loads prior to EDG load testing). The allocation of resources for maintenance and surveillance activities at some sites is inadequate.
13. The material condition of E&BP equipment varied from site to site and from facility to facility. Most E&BP installations were found in good condition, with equipment in a clean and well-kept state. However, there were a number of instances of poor equipment condition (degraded or missing parts, lack of cleanliness, oil leaks, corrosion, etc.) and adverse environmental conditions.
14. Data sheets used to record maintenance and surveillance activities often did not (1) include sign-off spaces for critical steps, (2) indicate specific parameters and their normal ranges to allow verification of proper operation, (3) provide instructions for what constitutes a failure or what to do in case of a failure, or (4) record as-found/as-left conditions, root cause information, or meaningful operating data for observing trends and anticipating failures. In some

instances a significant amount of testing was done but no records were kept.

15. The AET found relatively few problems with EDG system engines or generators. The EDG support systems (i.e., starting system, fuel system, cooling system and lubrication system) and associated electrical equipment (e.g., transfer switches, circuit breakers, interlocks and controls) were larger contributors to EDG system failure. Problems associated with batteries in EDG starting systems were the dominant contributor to EDG failures. Although significant improvement has been made in battery maintenance and testing programs at some sites, battery maintenance and surveillance programs at many sites were found to be weak, and often did not conform with current standard industry practice.
16. The EDG systems are often not equipped to readily allow performance of load tests. The EDGs at DOE facilities are, for the most part, tested at or near no-load conditions which does not demonstrate capability of the machine to perform acceptably on an actual demand.
17. At many sites there was either no program for preventive maintenance of UPS systems, or maintenance and testing practices were not consistent with industry standards. Maintenance for UPSs is inconsistent among sites and among facilities at a given site. Of particular concern was the number of UPS installations exposed to detrimental environmental conditions, specifically high ambient temperatures.
18. Automatic Transfer Switches (ATS) are widely used in UPS and EDG applications. The failure of an ATS to perform its design function of power transfer during a loss of normal power condition has the same effect as failure of the emergency source itself. Failures of ATSS have resulted in loss of both the normal power source and its associated E&BP supply. The AET found a general lack of preventive maintenance and testing of ATSS at DOE sites.
19. The AET found instances of incomplete post-maintenance testing and failure to require or perform post-maintenance testing. Post-maintenance testing is necessary to assure that the maintenance activity has been properly implemented and is effective, and has not induced other failure mechanisms.
20. The quality of data being input to the ORPS for E&BP supplies is often poor; many of the reports reviewed by the AET were inaccurate, missing relevant information and/or contained extraneous information. The causes given for failures were sometimes incorrect, partially because of the lack of involvement of technical experts in the reporting process. Additionally, the AET became aware of a number of failures that were not reported.

1.2 Recommendations

1. Conduct a workshop on emergency and backup power supplies for DOE Headquarters, Operations Office, and Contractor personnel responsible for the design, maintenance, and operation of E&BP equipment. The purpose of the workshop would be to establish and promote communications and sharing of information and technical expertise between DOE sites regarding operating experience, effective programs and practices, solutions to problems, and methods for improving the performance of E&BP supplies. The workshop should provide the findings and recommendations of the AET review of E&BP systems, and should include presentations from E&BP equipment vendors on recommended maintenance practices. The workshop should stress the importance of understanding the safety significance of E&BP supply applications, provide guidance on how to analyze and document the safety significance of E&BP supplies, and emphasize the need for E&BP supplies important to safety to be identified, classified, recognized, and treated as such by designers, users, and maintainers.

Status of Recommendation: Implementation of this recommendation is complete. A workshop on emergency and backup power supplies was held in Albuquerque on June 8-10, 1993. The workshop was jointly sponsored by DP-9 and the Office of Engineering and Operations Support (DP-62), and was attended by DOE Headquarters, Operations Office, and contractor personnel. Discussions and presentations included the results of the AET review of diesel generator, uninterruptible power supply, and battery systems, equipment vendor recommended maintenance practices, and methods used to improve design, operation, and maintenance of E&BP supplies.

2. Form a **BACKUP POWER WORKING GROUP (BPWG)** consisting of DOE and contractor representatives from each DP site where E&BP supplies are used to provide backup power to systems and equipment important to the safety of workers, the public, or the environment. The BPWG would provide a forum for effective communications on a continuing basis between DOE Headquarters, Operations Office, Area Office, Site Office, and Contractor personnel responsible for the design, maintenance, and operation of E&BP equipment.

Status of Recommendation: This recommendation is being implemented. A BPWG has been established. The first BPWG meeting was held in September 1993 at LLNL. Specific topics addressed included design, installation, and maintenance requirements for E&BP supplies, and disposition of several of the AET recommendations, as indicated below.

3. Consider requiring a formal analysis of loss of normal facility power in conjunction with single failures within the emergency/backup power system for Nuclear Hazard Category 1 and 2 Facilities, as defined in DOE Standard 1027-92 "Hazard Categorization and Accident Analysis Techniques for Compliance with DOE Order 5480.23, Nuclear Safety Analysis Reports." The loss of power analysis should address the probability and consequences of E&BP system failures and should

identify equipment and personnel actions necessary to ensure protection of workers, the public, and the environment. The level of detail required and magnitude of resources expended for the analysis would be determined using a graded approach. The analysis results should be formally documented and updated as necessary to reflect current facility hazards and the E&BP system configuration.

Status of Recommendation: This recommendation is being considered by DP-62 in their ongoing activities to provide guidance concerning analyses required to satisfy the requirements of DOE Order 5480.23, "Nuclear Safety Analysis Reports."

4. Promote maintenance and surveillance practices for E&BP system equipment consistent with accepted good engineering practices embodied in industry standards, and provide guidance on how to monitor, assess, document, and trend equipment performance for the purpose of maintaining E&BP system reliability and availability at acceptably high levels. This guidance should include standard definitions for use throughout the DOE complex concerning what constitutes: (1) E&BP system operability, (2) successful E&BP system operation, and (3) E&BP system failures, including what types of failures should and should not be reported in accordance with DOE Order 5000.3R, "Occurrence Reporting and Processing of Operations Information." The guidance should include the information to be recorded on data sheets used to document maintenance and surveillance activities.

Status of Recommendation: This recommendation is being implemented by DP-62 through their effort to issue a Standard, entitled "Backup Power Supplies For DOE DP Facilities." The Standard, which is currently in draft form, consolidates accepted maintenance and surveillance practices for E&BP system equipment from a number of industry standards, and provides guidance concerning monitoring, recording, and assessing E&BP system performance. The guidance provided in the standard is not intended as requirements, but rather as methods and approaches that are consistent with accepted industry good engineering practices, and which should be considered to achieve E&BP system conformance with DOE Orders.

5. Issue a DP Safety Information Letter (SIL) that: (1) documents DOE's policy concerning the need for an effective "Maintenance Management Program" in accordance with DOE Order 4330.4A that ensures high reliability of equipment important to the safety of workers, the public, and the environment; (2) addresses the need to establish overall organizational responsibilities and authorities for maintenance of E&BP system equipment and for ensuring that E&BP system reliability and availability are maintained at acceptable levels; and (3) emphasizes the need for M&O contractor upper management commitment and support to maintenance organizations responsible for E&BP equipment, including sufficient funding and cooperation from site program organizations and facility managers.

Status of Recommendation: This recommendation is being reviewed by the DP staff for appropriate action.

6. For those applications where redundancy is provided to improve E&BP supply availability/reliability, but where single point failure vulnerabilities have been identified that can compromise the redundancy, determine if modifications to provide true redundancy of equipment for accomplishing safety functions are cost beneficial.

Status of Recommendation: This recommendation has been given to the BPWG for disposition.

7. Assess the need for design improvements to existing lightning protection circuits to reduce the frequency and duration of power losses caused by lightning at Nuclear Hazard Category 1 and 2 Facilities where electrical power is important to the health and safety of workers, the public or the environment.

Status of Recommendation: This recommendation has been given to the BPWG for disposition.

8. The following recommendations concern maintenance practices for E&BP equipment. The AET believes that existing industry standards (e.g., published by the Institute of Electrical and Electronics Engineers), DOE Order 4330.4A, "Maintenance Management Program," DOE Order 5480.23, "Nuclear Safety Analysis Reports," and current initiatives such as upcoming efforts to improve configuration management programs at DOE sites, should form the fundamental basis necessary to ensure the proper design, operation, and maintenance of E&BP equipment important to safety. The recommendations below provide additional specific considerations for improved E&BP system performance.

- a. Develop and implement specific guidance for the design, operation, and maintenance of EDG starting system batteries and chargers to ensure reliable performance, including how to monitor and assess performance, and replacement considerations.
- b. Develop and implement specific guidance for performing EDG load tests consistent with manufacturer recommendations. Consideration should be given to improved EDG designs that facilitate load testing without the need to remove and reconnect cables.
- c. Review E&BP equipment installations to identify and correct deficient material conditions. Particular emphasis should be placed on verification that operating environmental conditions for UPS systems and electrical/electronic equipment (e.g., transfer switches, circuit breakers, monitoring and protective instruments and circuits) are consistent with the manufacturer's specifications.

- d. In view of the widespread use and importance of automatic transfer switches (ATSs) in providing E&BP, develop and implement a preventive maintenance and testing program for ATSs based on manufacturer's recommendations.
- e. Review work control systems and procedures to ensure that post-maintenance testing is required where necessary to demonstrate that maintenance or repair activities are properly implemented and effective, have not induced other failure mechanisms, and that equipment is properly returned to service.

Status of Recommendation: This recommendation has been given to the BPWG for disposition.

2.0 INTRODUCTION

2.1 Background

The DOE DP Office of Self-Assessment (DP-9) conducted a comprehensive review to assess the reliability and availability of E&BP system equipment at DOE nuclear facilities. This effort was initiated in response to DOE management concerns over the number of reported failures of E&BP systems to provide power during tests or actual demands. These concerns are documented in a memorandum, "Emergency and Backup Power Supplies," dated September 13, 1991, from former Secretary of Energy James D. Watkins to DOE Field Office Managers.

A review of ORPS data for failures of E&BP sources from September 1990 to September 1991 suggested that the number of failures was increasing and that the number of failures during actual loss-of-power demands was significant as compared to the number of failures during scheduled tests and surveillance (31 of the 77 failures reported were failures on demand¹). The ORPS data identified EDGs as the dominant contributor to power supply failures (46 of the 77 failures involved EDGs, as opposed to other sources such as batteries, motor-generator sets, etc.). Therefore, DP-9 dispatched an AET to the RF, RL, and SR sites to investigate EDG failures and to assess overall EDG performance. The RF, RL, and SR sites were chosen because they were the leaders in numbers of reported EDG failures (both diesel and gasoline driven engine generators). The objectives of these initial AET investigations were to collect, analyze, and document factual information concerning the causes, conditions, and circumstances surrounding EDG failures, to conduct a preliminary assessment of the safety significance of the failures, to determine the safety implications for DOE facilities, and to identify appropriate follow-on actions necessary to complete the overall assessment of the adequacy of emergency and backup power systems.

The findings from the initial AET effort are documented in Report No. DOE/DP-0098T "Augmented Evaluation Team Interim Report; Emergency Diesel Generator Reliability at DOE Facilities," dated April 1992. The report identified problems associated with starting batteries as the dominant contributor to EDG failures, and found that battery maintenance and testing programs were often weak and did not conform to current industry recommended practice. Therefore, DP-9 recommended that the AET review be expanded to include batteries used in other standby power applications such as UPS systems. For many facilities, UPS systems are considered more important to safety than EDG systems.

¹ As discussed in Chapter 4 of this report, a subsequent and more detailed review of ORPS data for events occurring over an approximate three year period showed that the majority of EDG failures were discovered during testing. Battery failures were also most often discovered during testing. The failure of UPSs were more commonly discovered while in service.

The DOE management authorized an expanded review to obtain information on UPS and battery systems and to supplement the initial findings concerning EDGs. Therefore, the AET visited a second group of sites: the NTS, LANL, Pantex, and the Oak Ridge Y-12 Plant. In addition, a return visit was made to SR.

This report documents the results of the AET review of emergency and backup power supplies (i.e., EDG, UPS, and battery systems) at the sites which participated in both the initial review (Phase I) and the subsequent expanded review (Phase II). The results of a joint appraisal of the LLNL emergency power system by the San Francisco Operations Office and DP-9, and DP-9 reviews of electrical distribution system transients and proposed modifications at SNL, are also factored into this report. The AET reviews were performed as part of the DOE Self-Assessment Program in accordance with the directives of Secretary of Energy Notice 6D-91. The plans developed and used for the AET on-site assessments are documented in memorandums from Donald F. Knuth, Director, DP-9 dated September 27, 1991 (Phase I) and February 7, 1992 (Phase II) "Augmented Evaluation of Emergency and Backup Power Supply Failures."

The AET reviews were coordinated and directed by DP-9. The AET included staff from DP-62, the various DOE Operations and Area Offices, and technical consultants with expertise in E&BP system design, operation, and maintenance at nuclear facilities from Brookhaven National Laboratory (BNL), Science Applications International Corporation (SAIC), LLNL, and Sciencetech, Inc. Appendix A provides a list of the AET members that participated in the on-site reviews and in the preparation of this report.

2.2 Review Scope and Methodology

The purpose of the AET review was to obtain a clear and factual understanding of the conditions and circumstances surrounding the performance of E&BP supplies. Objectives of the AET review were to promote an awareness of good engineering practices for E&BP equipment, and to provide recommendations, where necessary, to enhance E&BP system performance and reliability.

The AET assessed E&BP supply performance from a systems-level perspective. All subsystems which could cause the E&BP source to fail to provide electric power to its buses were included in the review. For example, typical subsystems for EDGs include the engine, the generator, associated electrical equipment such as output breakers and automatic transfer switches, and support systems such as battery-powered starting systems, fuel systems, lubrication systems, and cooling systems.

The on-site portion of the assessment included interviews with key M&O contractor personnel who were directly involved in the design and daily operation, maintenance, testing and surveillance, and engineering and technical support for E&BP systems. The AET conducted field walk-downs of the systems to assess equipment material condition and operating environment.

The first step of the AET reviews was to identify all E&BP equipment on site, and then to determine their general service areas, loads and functions. The reviews concentrated on E&BP equipment installed at facilities with nuclear hazards, or whose failure appeared more likely to jeopardize the safety of personnel or the DOE mission. Engineering judgment of the AET members was used to determine which E&BP systems are most crucial to the health and safety of workers, the public, the environment, or that have a substantial impact on the DOE mission. The E&BP systems that provide power solely to security systems and equipment, and general service to administrative buildings, were excluded from detailed review.

The AET attempted to identify E&BP system loads and their functions, and to assess the safety significance of E&BP supply applications and the consequences of failures. The AET reviewed SARs and other design basis documents, where available, to identify design basis requirements and safety functions for E&BP equipment, assumptions regarding the reliability and availability of E&BP supplies, and accident/emergency conditions where E&BP was required.

Prior to each on-site review, the AET established contact with DOE Operations and Area Offices and M&O contractors to explain and coordinate review activities and to obtain as much information for pre-site review as possible. The AET requested the following information from each site.

- The E&BP equipment identification numbers, manufacturers, model numbers, ratings/capacities, dates of purchase/installation, nominal full load values, physical location, electrical design configuration, and operating status (e.g., whether EDGs were normally running or on standby).
- Names, functions, and hazard classifications (high, moderate, or low) of the facilities containing equipment receiving power from each E&BP system.
- Descriptions of load functions (e.g., pumps for process cooling, fans for room or glovebox ventilation, emergency lighting, fire and radiation alarm systems, security equipment, etc.).
- The design basis for providing E&BP capability (e.g., to ensure controlled process shutdown, to ensure continued operation through unscheduled power outages, to maintain operability of systems important to worker safety, to ensure operability of equipment needed for accident mitigation, to prevent loss of process data, etc.).
- Identification of preventive maintenance (PM) tasks (including surveillance tests) for E&BP equipment, task scope and frequencies, the organizations performing the PM, and whether PM is conducted in accordance with manufacturer's recommendations.
- The E&BP equipment performance history and reliability. For example, the AET requested the following data for each attempted EDG start: the circumstances surrounding the start (e.g., loss of power, testing,

etc.), whether the start was successful (i.e., start and run and load and supply power to its bus for the required duration), the duration of the run, the conditions of the run, any unexpected conditions or problems encountered and cause(s) of failure(s), and any subsequent corrective actions.

The AET also attempted to identify existing practices or design features (or lack thereof) that could affect E&BP system performance and reliability. This included design considerations such as whether single failure vulnerabilities existed, and the criteria, codes, and standards applied to design, operation, and maintenance of the equipment. The E&BP system modifications, and programmatic issues that can affect E&BP system reliability (e.g., accuracy of drawings and management and engineering support) were also reviewed.

To assess the level and quality of maintenance practices and surveillance/testing, the AET reviewed maintenance and surveillance practices and procedures, including data sheets, acceptance criteria, and post-maintenance testing. The operational structure of maintenance organizations and maintenance management techniques used to plan, schedule, and coordinate maintenance activities were reviewed, including how PM data was recorded, collected, controlled, evaluated to trend and improve E&BP system performance.

Finally, the AET performed detailed reviews of those E&BP supply failures listed in the ORPS to obtain more complete and accurate information and to ensure that the failures were fully understood. This included confirmation of direct, contributing and root causes for failures, and the safety implications of failures. The causes for losses of normal power that result in demand challenges to E&BP systems were also reviewed.

The AET review was not intended to identify violations of rules or requirements, but rather to understand the circumstances and conditions surrounding the design, operation, and maintenance of E&BP systems, and to promote good engineering practices for E&BP equipment. Prior to leaving each site, the AET held an exit meeting where the findings of the on-site review were presented. The AET attempted to present the findings in a positive and constructive manner in the hope that those E&BP systems important to safety would receive increased attention to enhance their performance and reliability where warranted. The AET has already seen some progress at most sites in this regard. The review included a large number of sites in order to get a clear overall understanding of areas that are generally in need of improvement, so as to make beneficial recommendations that lead to enhanced E&BP system performance consistent with mission and safety objectives.

The results of the AET reviews are presented in the following sections of this report.

3.0 POWER SYSTEM DESCRIPTION

The sites and facilities visited by the AET exhibited diverse and somewhat unique approaches in the configuration of their off-site and on-site electric power systems. This is largely due to the manner in which the sites have evolved over many years, often necessitating numerous modifications to the electrical power system as new facilities were built and existing facilities were modified. Some site electrical distribution systems were originally installed decades ago (e.g., in the 1940s), and have been added to in a piecemeal fashion to keep up with growing power needs. The result is electrical system designs that often consist of a variety of different types of equipment. This section describes typical power distribution system designs that support these facilities, and the E&BP equipment provided to supply power to facility loads following a loss of the normal power source. The causes for loss of normal power which result in challenges to the E&BP system, and the safety classification assigned to electrical system equipment are also discussed.

3.1 Off-site and On-site Power Distribution Systems

In general, the power distribution system consists of incoming lines supplying power from off-site sources, a fairly extensive on-site distribution system that provides power to hundreds of facilities, and a large number of on-site power supplies, specifically EDG, UPS, and battery systems. These are discussed briefly below to provide background information relevant to the findings, recommendations and conclusions in this report.

The off-site power supplies to each of the sites visited consisted of at least two incoming lines, with some degree of independence; e.g., different substations and/or off-site supply voltage levels. Larger sites have additional redundancy; for example, one large site has three available off-site sources, two of which are capable of supporting the entire site load demand. Another site has four feeder lines serving the on-site switchyard. Practically all off-site and most on-site power distribution is via overhead lines. Some sites use underground distribution circuits to varying degrees.

The interruption of power to an entire site has seldom occurred because of the redundancies discussed. Personnel at some sites could not recall any complete loss of off-site power. However, interruptions in the off-site and on-site power systems have resulted in the loss of normal power to numerous facilities. Individual facilities generally are more susceptible to power losses caused by equipment failures because the power feeds are typically not redundant. Portions of a site are sometimes only supplied by a single feeder such that its loss directly affects the supply of normal power to all facilities located in that area. Some sites have added redundancy to portions of their power distribution systems that supply critical facilities to help ensure the availability of normal power despite single failures of off-site or on-site power distribution system equipment.

3.1.1 Causes for Loss of Power

The largest contributor to losses of off-site power is lightning. Analysis of data at one site concerning losses of off-site power shows that 70 percent of all power losses due to external causes from 1981 to 1991 were weather related, and that 70 percent of those were caused by lightning. For this site, one half of all externally caused power outages were the result of lightning.

At another site, an informal log of electrical power outages (from October 1987 to September 1991) kept by personnel responsible for operation and maintenance of the high voltage on-site distribution system also showed that the largest contributor to power outages was by far weather related (high winds, lightning, thunderstorms, and snow). There were incidents caused by equipment related failures (e.g., transformers or switchgear), including some that appeared related to problems with aging equipment and cables. There were eight events that were related to human error (a couple of these involved operation of the wrong equipment, but most were caused by subcontractors digging or running into power lines with heavy equipment during construction activities). This was found to be common to other sites as well. One site had several incidents where power was lost when power lines were contacted by repair truck booms. Another site experienced several outages from digging into buried duct banks with drilling or trenching equipment.

At another site, the causes for 43 out of 121 unplanned outages (or 35 percent) occurring in 1991 and 1992 were weather related and lightning was again the dominant cause. The next largest contributor to unplanned outages at this site was equipment failures (37 out of 121, or 30 percent); this percentage is higher than that for some other sites and is attributed to the physical size of the site and aging distribution system equipment. Other causes for unplanned outages include personnel error and animals (e.g., coyotes and ravens). Large birds were identified as a relatively common cause for outages at other sites.

The AET also reviewed site records to determine the typical lengths of time required to restore normal facility power following unplanned outages. At one site, the average duration of the twelve unscheduled outages in 1989 was 3 hours and 40 minutes, and approximately 3-1/2 hours for the seven unscheduled outages in 1987. For several other years, this site experienced as few as one or two unplanned outages. At another site, the AET documented the duration of 79 outages occurring in 1991. Twenty-five of the outages were momentary, nine were for five minutes or less, eight lasted between five and 30 minutes, six lasted for between 30 minutes and one hour, and 31 lasted for more than an hour. Of these 31, approximately half lasted for over five hours, with six lasting for at least a day.

In addition to permanently installed (dedicated) E&BP supplies, most sites have a number of portable emergency generator units that can be connected to individual facility load centers to provide temporary facility power until normal power is restored. However, the time required to connect portable generators varies depending on availability, facility location, and ease of

hookup. A few facilities are equipped with permanently installed terminations that permit fast hookup to portable units.

The above examples are typical in that lightning was cited as the major contributor to loss of power events at practically all sites visited by the AET. These loss of power events generally result in a demand to start a standby generator if power to a critical facility is affected (e.g., a facility where electric power is relied on to monitor and/or ensure worker safety from nuclear hazards). One site significantly reduced the effects of lightning related problems on their electrical system by installing underground distribution and feeder circuits and improving their lightning protection circuits. Some facilities cease operations if lightning is in the area (e.g., facilities that contain high explosives; these facilities typically had the best lightning protection).

Site distribution system power losses affecting one or more facilities are not uncommon. The loss of normal power to a given facility that challenges the facility E&BP system is clearly a credible occurrence and should be expected. Improvements in lightning protection schemes may considerably help to reduce losses of normal facility power and the resulting demands on backup power systems within the DOE complex. Therefore, the AET recommends that M&O contractors assess the need for design improvements to reduce the frequency and duration of power losses caused by lightning at Nuclear Hazard Category 1 and 2 Facilities where electrical power is important to the health and safety of workers, the public or the environment.

3.1.2 On-site Power Distribution

Due to the large areas and multitude of buildings which comprise the DOE sites, the on-site distribution system performs an extremely important function in assuring a continuous and reliable source of power to important loads. The on-site distribution system primarily consists of substations, which transform incoming power from off-site to values suitable for transmission across the site, and transmission and distribution circuitry and switchgear to provide power from the substations to individual facilities. Typically, the capability exists to isolate electrical faults and reroute power via alternate circuits to enhance availability. The on-site distribution system is under the control and responsibility of the site operations and maintenance organizations. On-site distribution circuits are typically 4.16kV or 13.8 kV, which is then transformed to 480 volts at the facility load distribution centers.

At one site, the AET was favorably impressed with the regular maintenance and surveillance activities performed on the on-site distribution system to achieve a high level of reliability. At another site, a recent improvement to the on-site distribution system was installation of an underground distribution loop consisting of parallel circuits, either of which can provide power to selected facilities and loads supplied by the loop. In addition, the loop can be fed from two different sources of normal power, or from any one of three 1100kW diesel generators. These generators start automatically on a loss of normal power.

Planned improvements to the on-site power distribution system at another site include 11 miles of new circuit to complete a loop, 20 miles of new circuit to add a redundant power supply to an important test area, and 4 miles of new line to provide a redundant source to two remote substations.

Modifications at another site included the addition of an independent connection to the off-site power grid, new on-site substations, and replacement of aged and degrading on-site distribution system equipment such as transformers, cables, and circuit switching devices.

Some of the reasons given for the improvements discussed are:

- (1) to replace 30 to 40 year old electrical distribution system equipment that has reached or is nearing the end of its design life;
- (2) to increase electrical system reliability and availability; and
- (3) to bring the site into conformance with DOE Order 6430.1A, "General Design Criteria," with regard to desired electrical power system redundancy.

The AET encourages continued upgrading of electrical distribution systems where reliable sources of power are relied on to assure performance consistent with safety and mission objectives.

3.1.3 On-site Power Supplies

In the event of an interruption of normal power due to a failure in either the off-site power system or the on-site power distribution system, equipment is available on-site to assure continuity of electric power for the continued safe operation or controlled safe shutdown of critical activities. These on-site power supplies, variously called emergency, standby, alternate, or backup sources, are referred to in this document as E&BP supplies, and consist primarily of EDGs, UPSs, and station batteries. At some sites, gasoline-fueled engine generators or motor-generator sets are used for this function. Diesel-fueled engine generators are the most common type of backup generator in use at both DOE and commercial nuclear facilities. For the purpose of readability, the term EDG, as used in this report, is intended to mean any engine driven generator, regardless of whether the engine is powered by diesel fuel or gasoline.

The typical EDG configuration used at DOE facilities is illustrated in Figure 3.1. As shown in the figure, there are a number of essential auxiliary support systems that must function properly if the EDG is to provide backup power as designed. In the typical installation, the EDG is normally in a standby status, i.e., not operating, but available to start in response to an automatic or manual initiation signal to provide power to essential loads through the ATS. There is an average of over 60 backup generators at each site, not including portable units, many of which are rated at less than 50 KW. The majority are more than 20 years old, with some close to 50 years old. Typical generator loads include fire alarm

Figure 3.1: Typical Engine Generator System

systems, radiation monitoring equipment, emergency lighting, and public address systems. Some generators have more specialized loads such as exhaust fans, security equipment, or process and process monitoring equipment.

The most common UPS configuration found at DP facilities is illustrated in Figure 3.2. The UPS is the final source of power for critical loads. Under normal operating conditions, the battery charger acts as a rectifier to provide DC power to the inverter from the normal AC incoming line. The battery is connected in parallel with the DC power being supplied from the charger so that if any failure or voltage drop occurs in the AC input line, the batteries will provide DC power to the inverter. In this manner, power is continuously supplied to the load for failures in the normal power supply. The battery continues to power the inverter until the battery output drops to a level that will no longer drive the inverter. How long the battery will drive the inverter depends on its ampere-hour rating (battery capacity) and the size of the inverter load. The length of time that the batteries will supply these loads varied from 15 minutes to 4 hours for different site applications. When AC power is restored from the normal power distribution system or the diesel generator, the rectifier-charger begins to drive the inverter and recharge the battery.

Typical UPS loads include criticality and radiation monitoring systems, critical process instruments and alarms, communication equipment, the fire protection system, and emergency lighting. Special instrumentation and controls are also supplied power from the UPS at some sites. UPS sizes ranged from small single phase 5 kilovolt-ampere (KVA) units with internal batteries to three phase 50 KVA fan-cooled units with external 60 cell battery banks. Basic operation of the units is the same, although the consequences of a loss of one of the larger units is expected to affect much more equipment than one of the smaller units. Equipment that is sensitive to power system perturbations, such as computers, is typically supplied from UPSs because they provide "clean" filtered power (i.e., the UPS output remains constant despite small variations or "glitches" at the input).

3.2 Equipment Classification & Terminology

3.2.1 Classification of Equipment

The graded approach to maintenance, quality assurance, and resource management requires that a level of rigor and attention be assigned to equipment and systems commensurate with their safety significance and mission importance. One of the objectives of the AET was to determine the safety classification assigned to E&BP equipment. The observations made by the AET in this area are summarized below.

The classification methodology for E&BP system equipment was technically sound at some sites, but not at others. The classification process was not well documented and not well understood at several of the sites. At two sites, the EDGs and UPSs are not classified at all. Identical classification designations had different meanings at different sites.

Figure 3.2: Typical Uninterruptible Power Supply

Personnel responsible for maintenance of E&BP equipment were often forced to make classification determinations without sufficient help from those most knowledgeable with facility operations and the potential consequences of E&BP supply failures. The site M&O contractor program organizations responsible for conducting facility operations, and not the maintenance department or DOE, are responsible for analyzing the safety significance of E&BP system equipment supporting their facilities and ensuring that the equipment is appropriately classified. As discussed in detail in Chapter 5 of this report, the safety implications of E&BP supplies at DOE facilities have not been well analyzed and do not appear to be fully understood. Despite these shortcomings, the attempts to classify equipment at a number of sites appeared reasonable, appropriate, and successful in terms of providing better maintenance for E&BP equipment important to safety. At a couple of sites there were EDGs with no significant role in accomplishing mission or safety objectives, that were classified at the highest significance level. Reasons given for classifying all EDGs as important to safety were: (1) it was considered a prudent and conservative approach since there was no analysis to determine the appropriate classification level; and (2) the maintenance department considered it easier to treat all EDGs the same. Specific classification levels used at DOE sites are described below.

The E&BP supplies at one site are classified in accordance with Attachment 1 "Categorization of Reportable Occurrences" to DOE Order 5000.3A, "Occurrence Reporting and Processing of Operations Information." The classification levels are: Class A equipment (any active or passive safety device/system or any primary environmental monitors), Class B equipment (any device/system which, although not primarily safety related, will result in facility shutdown or degradation of operating parameters, or any secondary environmental monitors), and Class C equipment (essentially all equipment not designated as Class A or B). At the time of the AET visit, approximately 10 percent of the EDGs were Class A. At a second site, E&BP equipment was also classified as Class A or B, but the classification in this instance referred to whether maintenance of the equipment was performed by a site-wide maintenance organization or was the responsibility of the program organization conducting operations at the facility where the equipment was installed. Some Class A and some Class B equipment was considered important to safety at this site. At a third site, one of two consequence-of-failure levels (CFL) are assigned to E&BP equipment: CFL-A for critical and safety system equipment, and CFL-B for the balance of plant. At this site, the CFL designation determines the controls (e.g., procedural formality and quality control) applied to maintenance activities.

At one site, E&BP equipment was assigned one of three categories: Category I which consists of equipment considered important to safety; Category II which consists of process/production related equipment that is not considered important to safety; and Category III which is the balance of plant equipment that is not significant to safety. The process for categorizing equipment appeared appropriate, but needed to be formalized. E&BP equipment important to personnel safety (e.g., providing backup power to fire or criticality alarms) are automatically assigned to Category I. Equipment categorization at this site determines the "level of rigor" applied to equipment maintenance activities. The AET was told that

essentially all EDGs were Category I equipment, but later found maintenance procedures that identified EDGs as Category II equipment.

At another site, the classification system had recently been revised to establish four categories:

- Nuclear Safety; includes the reactor coolant pressure boundary, and systems associated with the prevention or mitigation of design basis accidents or an unplanned criticality, and systems needed to monitor releases.
- Critical Protection; components or systems whose failure would prevent operation of Nuclear Safety equipment or could cause toxic release to the environment.
- Production Support; production-oriented systems and components.
- General Services; support systems with no safety significance.

Some E&BP equipment is classified as Nuclear Safety and some is classified as Critical Protection. Many UPSs are classified as Production Support. The rationale behind the classifications was sometimes not clear.

3.2.2 DOE Guidance for Classification of E&BP Equipment

DOE is planning to issue a Standard on configuration management entitled "Implementation Guide for Operational Configuration Management Programs, Including the Adjunct Programs of Design Reconstitution and Material Condition and Aging Management." The latest draft of the Standard provides guidance for assigning grades to systems, structures, and components (SSCs). The SSC grades, or classification levels, are a measure of the importance of the SSCs within the facility that can be used to determine priorities for attention and resource allocation. Grading SSCs by importance is needed to determine the level of controls required for configuration management functions such as change control and document control, and is necessary for site/facility programs such as the maintenance program, SAR update program, and Quality Assurance (QA) program. The equipment design requirements determine the grades assigned. The Standard gives the following four categories of SSC grades:

- Nuclear Safety (e.g., necessary to prevent or mitigate consequences from nuclear hazards to facility workers and to personnel both on-site and off-site);
- Environmental, Safety, and Health (ES&H) (e.g., necessary to prevent or mitigate consequences from non-radiological hazards, such as toxic or chemical hazards, or to provide worker health or industrial safety, or protect the environment);
- Mission Critical (e.g., necessary to prevent substantial interruptions in facility operation or severe cost impacts); and

- Designer Option (e.g., provided for ease of operation, testing or maintenance, or security and safeguards considerations).

Section 1300-3, "Safety Class Criteria," of DOE Order 6430.1A, "General Design Criteria," states that safety class items are those systems or components which are required for nuclear criticality safety, required to monitor the release of radioactive materials to the environment, or required to maintain operating parameters within the safety limits specified in the TSRs during normal operations and anticipated operational occurrences.

One of the industry standards referred to in DOE Order 6430.1A for guidance in evaluating the safety classification of the electrical systems is National Fire Protection Association (NFPA) Standard 110, "Standard for Emergency and Standby Power Systems." Appendix A of this standard contains two definitions (level 1 and level 2) relative to the classification of E&BP equipment and systems described in this report.

Typically, level 1 systems are intended to automatically supply lighting or power to critical areas or equipment in the event of a loss of normal power. According to NFPA 110, emergency systems (level 1) may provide power for such functions as ventilation, fire detection and alarm systems, or "industrial processes where current interruption would produce serious life safety or health hazards."

Level 2 systems are "intended to automatically supply power to selected loads (other than those classed as emergency systems) in the event of failure of the normal source." The standard states that the typical loads supplied by level 2 power sources are heating and refrigeration, communication, and "industrial processes that, when stopped during any interruption of the normal electrical supply, could create hazards or hamper rescue or fire fighting operations."

The final draft of DOE-DP-HDBK-3002-92, September, 1992, "Defense Programs Non-reactor Nuclear Facilities: Standards and Criteria Guide," provides guidance on safety class electric power systems. Several quotes applicable to this review are offered as background information:

- "The safety function of the safety class electrical system is to provide sufficient power of suitable quality to safety class systems and equipment in order to assure their ability to perform their safety functions when required. This system includes an on-site electric power source to supply safety class systems when off-site power is not available."
- "The on-site safety class power supply requirements should be defined on a case-by-case basis with type and capacity of power source selected to meet the specific engineered safety feature system requirements at the non-reactor nuclear facility."
- "The facility operator should be provided with bypassed and inoperable status indication, when necessary, to indicate that portions of the

safety class electrical power system have a reduced operational capability due to maintenance or testing in progress."

In general, the AET found that progress has been made at most sites to classify the safety significance of E&BP system equipment. This is an essential part of responding to DOE Order 4330.4A, "Maintenance Management Program," DOE Order 5480.23, "Nuclear Safety Analysis Reports," and other Orders which proffer the graded approach to resource allocation. However, support systems (such as those supplying electrical power) have not typically been addressed by the SARs. It was not clear that the safety significance of electrical power failures is well understood, making it difficult to assign a safety level or class.

There are advantages to consistent equipment classification levels being applied throughout the DOE complex, such as consistency in occurrence reporting and implementation of DOE Order 4330.4A, "Maintenance Management Program." The safety significance of E&BP supplies needs to be fully understood so that those supplies important to safety are identified, classified, recognized, and treated as such by designers, users, and maintainers. Although progress is being made in these areas, proper classification of E&BP equipment cannot be assured until the safety significance of the equipment has been adequately analyzed. Chapter 5 of this report provides the AET's recommendations in this area.

4.0 OCCURRENCE REPORTING AND FAILURE ANALYSIS

4.1 Data Acquisition

This analysis addressed three different types of E&BP systems: EDGs, UPSs, and independent battery systems. The EDGs (diesel and/or gasoline driven engine generators) included those in emergency service (necessary for safety reasons) as well as those in backup service (not necessary for safety, but desirable for other reasons such as mission continuity). While UPSs are most commonly provided for emergency service, they are also often provided to assure a continuous source of "clean" power (i.e., power that is regulated and filtered to provide a high quality source of constant output power that is not affected by minor perturbations or transients on the AC input line) for process control computers and data monitoring systems.

The EDG and UPS systems require battery power for proper operation. At most DOE nuclear facilities, EDG starting power is supplied by batteries. The UPS systems use batteries as the power source when normal power is not available. Battery chargers are provided for both EDG starting and UPS batteries. The chargers supply the normal source of power until their AC input becomes unavailable, at which point the batteries take over and supply power until the AC input is restored. Because the batteries and chargers are integral to the EDG or UPS system, this analysis treated them as components of the EDG or UPS system.

In addition to the batteries associated with EDGs and UPSs, many facilities have separate independent battery systems dedicated to specific purposes, such as for fire protection systems, radiation monitors, toxic gas monitors, criticality detectors, evacuation systems, and the operation of switchgear for power distribution systems. These types of battery systems were treated separately from the EDG and UPS batteries.

At some DOE facilities, steam power is provided as a source of backup power. This analysis did not address non-electrical power systems. Also as a general rule, this analysis addressed only those E&BP supplies in service at Defense Programs facilities.

Three sources of failure data were used in this analysis: (1) the DOE ORPS database, which includes the occurrence reports submitted in response to the DOE Order 5000.3, "Occurrence Reporting and Processing of Operations Information," (2) the DOE Office of Nuclear Safety (NS) Operating Experience Weekly Summary Reports, which often include more detailed information on specific E&BP failure events, and (3) the Secretary of Energy Daily Operations Brief, which sometimes includes information on E&BP system failures.

The ORPS system was searched for E&BP system failure occurrences using a particular set of search conditions. First, the search was limited to occurrences at facilities assigned programmatically to DP. Second, preliminary Notification reports were excluded, because they typically lack detailed information and the vast majority of them had been superseded by subsequent 10-day and final reports. Third, a narrative search based upon

key words was used to identify the pertinent occurrence reports. For this analysis the key words were: Emergency Diesel, Diesel Generator@, UPS, Uninterruptible, and Batter@, where the symbol "@" is a dummy entry which allows any following characters to be included in the search. Using this entry permitted capturing both the singular and plural forms of particular words.

The ORPS searches yielded 174 occurrence reports for the first set of key words (EDGs), 167 reports for the second set of key words (UPSs), and 283 reports for the third set of key words (Batteries). The NS weekly summaries yielded about 30 occurrences, and the Secretary of Energy Operations Briefings yielded about 20 occurrences. These data sources yielded a total of more than 600 occurrences.

The occurrence dates ran from the third quarter of calendar year 1990 through the second quarter of calendar year 1993, for a total span of more than two and a half years. There were over 600 reported occurrences during this period. Each occurrence report is a separate database record. Within each record, each data field contains a specific bit of data, such as the name of the facility or the date of the occurrence. Some fields, such as the dates and times of certain notifications, were not pertinent to this analysis and were deleted.

Unlike reports printed directly from ORPS, downloaded ORPS files do not contain all information in the occurrence reports. Instead, they contain the code numbers and symbols that represent certain conditions. For example, the nature of the occurrence might be shown by the code "1E" which corresponds to a Vital System/Component Degradation. Similarly, an occurrence cause factor might be shown by the code "4B" which corresponds to an Inadequate or Defective Design. A set of supplemental databases was developed and linked to the failure databases to correlate these codes with the word meanings, and to enter these descriptive words into the failure databases in place of the ORPS codes.

Previous experience with using ORPS data has shown that the reports do not always highlight the specific information of interest in a particular review, and in some cases the cause determinations may be missing or inaccurate. Therefore, the AET independently reviewed the available information to make technical judgements regarding the systems involved and the cause factors.

New data fields were added to provide a place to enter additional review information. These fields included considerations such as when the failure was discovered (e.g. during an actual demand, or during scheduled periodic testing), whether or not a failure of an E&BP system was actually involved (versus the reporting of a power outage during which the E&BP system performed properly), what type of E&BP system had failed and which subsystem, whether the system was nuclear safety related, and whether the "failure" adversely impacted the operability of the system (versus a missed surveillance test for example).

In addition, special data fields were added to address the independent determination regarding cause factors. The direct cause, up to three contributing causes, and the root cause were addressed. For each failure, a cause code was entered (using the ORPS coding system plus two additional cause categories) and comments were provided. Finally, a general comments field was added.

4.2 Technical Review

The technical review of this operational experience involved two distinct parts. First, each individual occurrence report was evaluated and the results entered into the databases. Second, the databases were reviewed to determine which sub-systems were involved most often, the safety significance, and the most frequent cause factors.

4.2.1 Individual Occurrences

Each occurrence report was reviewed individually. These reviews consisted of two parts; first a set of general categorization questions for each occurrence, and second, an independent judgement of the cause factors.

General Categorization Questions

The first question was whether the report identified an actual failure of an E&BP system or component. Some occurrence reports describe an incident involving a loss of normal power where the E&BP system performed properly. In other cases, an E&BP system was mentioned only in a peripheral sense. Occasionally, the report described a situation not related to the operational E&BP system, for example, dropping new batteries during delivery and creating an environmental "spill." A significant number of the initial occurrence reports were excluded from further consideration because they did not involve an E&BP system failure that caused a loss of functional capability.

The second question concerned the type of E&BP supplies that failed (i.e., EDG, UPS, or Battery system) and which sub-system had failed. To facilitate this portion of the analysis, a list of sub-systems was established for each type of E&BP supply.

The sub-systems for EDGs are:

- Fuel System,
- Starting System (including Starting Batteries and chargers),
- Speed/Voltage Control,
- Engine,
- Generator,
- Cooling System,
- Lubrication System,
- Protective Relaying (e.g. Overspeed trip),
- Support Electrical Equipment (e.g. breakers and transfer switches), and
- Unknown.

The sub-systems for UPSs are:

- Batteries,
- Protective Devices (i.e., fuses and breakers),
- Inverters,
- Control Circuit Boards,
- Capacitors, and
- Unknown.

The sub-systems for Battery Systems are:

- Batteries,
- Chargers,
- Support Electrical Equipment, and
- All Others.

The third question was whether the E&BP system appeared to be in a safety-related application. For example, one EDG may provide power to emergency systems for a nuclear facility, another EDG may supply a non-safety backup system (e.g., providing power for air conditioning of an administration building).

The fourth question was whether the reported occurrence appeared to impact the operability of the E&BP system. For example, if the capacitors in an UPS had failed, the UPS would no longer be able perform its intended function. Conversely, if a periodic surveillance test had not been performed within the scheduled period, this would not indicate that a failure of equipment had occurred.

The answers to each of these categorization questions were entered into the databases.

Cause Factors

Some occurrence reports do not include data for the direct cause, contributing causes, or the root cause, even though the reports might have been the Final Occurrence Reports. In some cases, the cause factor categories available in the ORPS system do not fit the situation very well, and a best-fit category is used. In other cases, the cause determinations may have been made by an individual who is not an expert on the technical aspects of E&BP systems. Some causes identified did not match the situation described in the occurrence report.

As each occurrence report was evaluated, the direct cause, contributing causes, and the root cause were identified. The cause factors used are the same as the ORPS categories, plus two additional categories. The first additional category was Maintenance. This category was used to indicate maintenance not performed (especially preventive maintenance), performed improperly, or situations wherein old equipment that should have been replaced earlier is being sustained by the maintenance department. The second additional category was Unknown. Some occurrence reports indicated

that the direct or root cause was "equipment failure", however, the report would state that the cause of the occurrence was unknown.

4.2.2 Overall Review

After each of the occurrence reports had been reviewed individually, the complete set of reports in each of the databases was analyzed as a single overall set. This review focused on several questions:

- Is the number of failures increasing or decreasing with time?
- When are most of the failures being detected (during testing, during actual power-loss demands, during in-service operations)?
- What sub-systems are the most troublesome for each type of E&BP system?
- What are the most frequent general root causes?
- Within the most frequent general root causes, what are the leading specific root causes?

Each of these questions was answered by performing "queries" on each of the failure databases and consolidating the results. The results were then developed into graphical format in order to identify any patterns or trends. The "outliers" (i.e. an inordinate result) on a particular graph became the target of the next questions. For example, if the most frequent EDG sub-system failure was the starting system, the next question would be: within the starting system failures, what is the distribution of the specific causes? There were no pre-determined followup questions; the initial results determined the next steps of the analysis.

Finally, some overall general conclusions were drawn from the results of the analysis, which are presented at the end of this report.

4.3 Results

The technical results of this analysis take the form of graphical depictions and observation comments. The results for EDG, UPS, and battery systems are presented separately because the nature of the systems are significantly different.

4.3.1 Emergency Diesel Generators

The overall review of EDG failures was limited to those EDGs that appeared to be in a nuclear safety application, and those failures that appeared to have adversely impacted the operability of the EDG system. This screening yielded 118 EDG failures which occurred over a period of 2-3/4 years. The following are the findings and conclusions for EDGs:

1. The distribution of EDG failures during the period of the third quarter of calendar year 1990 through the first quarter of 1993 (11 quarters of failure experience data) indicates a relatively even pattern, with only

one "outlier." An inordinate number of EDG failures occurred during the third quarter of 1991. These failures were reviewed in further detail in an effort to determine the cause of this anomalous situation. The only identifiable factor was that the vast majority of these failures were at either of two sites; however, no particular facilities contributed an extraordinary number of failures.

2. As shown in Figure 4.1, EDG failures were discovered most often during scheduled periodic testing rather than during actual loss-of-power demands on the EDGs. This is attributed to EDGs being in a standby mode of service where they are not operated for long periods of time such that failures are more likely to be detected during test runs which occur more frequently than actual demands.
3. As shown in Figure 4.2, the EDG sub-system failures appear to be dominated by two of the ten sub-systems: starting systems and supporting electrical equipment. Most of these sub-system failures involved the starting batteries (or the battery charger) and circuit breakers.
4. As shown in Figure 4.3 the general root cause for EDG failures are frequently listed as unknown. Where the general root causes of EDG failures have been identified, they are predominately in three of nine areas: Equipment Problems, Design Problems, and Maintenance Problems.
5. The majority of the EDG failures in the category of Equipment Problems were caused by failed parts. The most frequent failures were the starting battery itself or the battery charger. In most of these cases the battery did not have sufficient remaining capacity to operate the starter motor, usually due to lack of charge and old age. In some cases, the charger had blown a fuse, allowing premature discharge of the battery (when the charger becomes inoperable, the battery supplies power to local instruments causing the battery to discharge, usually within several days). Degraded charger and battery conditions in EDG starting systems are typically not alarmed, and therefore, are not detected until the next scheduled surveillance. In a few cases the starter solenoid failed, leaving the starting battery disconnected from the starter motor.

In some cases, electrical breakers failed due to improper reinstallation after testing or maintenance. Occasionally, the breaker in the normal power system designed to trip upon the loss of normal power did not trip due to the failure of the undervoltage trip device. Operating experience with E&BP systems in the commercial nuclear industry has demonstrated that breaker failures are often the result of improper maintenance. Thorough breaker maintenance programs in accordance with manufacturer recommendations can significantly improve reliability and extend service life.

6. The review of occurrence reports where the general root cause is identified as a Design Problem showed cases which illustrate the

HOW EDG FAILURES WERE FOUND

July 1990 through March 1993

FIGURE 4.1

EDG SUBSYSTEM FAILURES

July 1990 through March 1993

FIGURE 4.2

EDG FAILURE GENERAL ROOT CAUSES

July 1990 through March 1993

FIGURE 4.3

susceptibility of some designs to single failures and cases where the design was inadequate.

Perhaps the most interesting design case is that of the ATS which is "shared" by the normal power system and the EDG. The ATS is typically designed and installed as an integral part of a motor control center in the normal power system. Due to the "Y" configuration of ATSs (i.e., two inputs, the normal power feed and the EDG backup feed, and one output supplying power to connected loads), their failure can cause a loss of both the normal power system and the backup power system that is intended to mitigate the loss of the normal power system. In some failure modes the ATS can cause the EDG to be connected to the normal power system, which could lead to damage of the EDG if appropriate protection is not provided. A design with two breakers (one feeding the bus from the EDG, the other, from the normal source) may be more flexible and tolerant of certain failure modes.

In a few cases, the cooling system was inadequately sized to provide sufficient cooling when the ambient temperature approached the top portion of the rated range. In other cases, the lubrication system did not include a "keep warm" heater and therefore allowed the viscosity of the lube oil to become so high during cold weather conditions that the starter motor could not start the EDG before battery capacity ran out or the "overcrank" trip occurred.

Some designs did not include provisions to detect an unacceptable battery condition. This is a common situation for EDG installations at DOE facilities. Since the battery charger provides the operating power until the normal power is actually lost, if the starting battery was degraded it would remain undetected and be left incapable of performing its design function. The inability to detect degraded battery conditions and to test batteries under actual loaded conditions is considered a design weakness that has a significant impact on EDG reliability.

7. The EDG failures in the category of Maintenance were caused specifically by lack of preventive maintenance and by old equipment long overdue for replacement. The majority of these failures involved either batteries or their associated chargers. There is also indication that the breakers in the normal power system interfacing with the backup power systems and which are designed to trip during loss of normal power had not received adequate preventive maintenance.

There is some indication that limited funding may lower the priority given by contractors to maintenance activities and equipment replacements (such as batteries). In some cases, these constraints may have contributed to EDG failures. Assigning a low priority to these activities can result in unanticipated failures.

8. The largest single root cause category for EDG failures was "Unknown." These failure reports were investigated to determine why so many were unknown, but no real reason could be found. The distribution with

regard to DOE sites showed no outliers. There was no particular pattern as to which sub-system failures were caused by unknown reasons. The only significant factor found was that most of the unknown failures were reported for actual demands on the EDG. There is often a temptation to bypass root cause analysis due to its inherent difficulty. However, avoiding this analysis will often result in experiencing repeated failures. If a root cause cannot be found, then the components whose failure would most likely produce the symptoms experienced should be identified and evaluated.

4.3.2 Uninterruptible Power Supplies

The UPSs are designed to be in continuous service to provide clean and reliable power to critical electrical loads that are sensitive to voltage transients such as digital electronic equipment. The UPSs also provide continuous backup power for momentary interruptions of normal power. The instantaneous switchover to battery power by the UPS is very important because the loads can be upset by even a brief interruption of power. In many systems, the UPS is designed such that power can be supplied from an EDG in addition to the normal power system so that the UPS batteries will not become discharged if the normal power outage lasts more than a few minutes.

Frequently, the design of the UPS includes an automatic transfer to "bypass" operation. The benefit of this feature is that if an internal UPS failure occurs during normal operation, the loads automatically switch to an alternate source of power without interruption.

For many DOE nuclear facilities, UPSs are provided for other than nuclear safety related purposes, such as computer control systems or fire alarms. Due to the nature of these applications, to consider only nuclear safety related applications of UPS would eliminate valuable failure experience data. Therefore, all types of UPS service applications were included.

Similar to the situation for EDGs, "failures" that did not impact operability were excluded. This screening yielded 49 UPS failures which occurred over a period of 2 3/4 years. The results presented below parallel the types of results presented for EDGs.

1. The pattern of UPS failures over the period did not indicate any anomalies.
2. As shown in Figure 4.4, and unlike the case for EDGs, most UPS failures were discovered while they were in service, followed by being discovered during an actual loss-of-power demand. This is attributed to UPSs normally being in continuous service and being dependent on the backup battery during loss of normal power. Also, the AET found that preventive maintenance programs for UPSs were generally not as thorough as those for EDGs.

3. As shown in Figure 4.5, most UPS failures appear to occur in two of the six subsystems: batteries and protective devices (fuses and circuit breakers).
4. As shown in Figure 4.6, the general root causes of UPS failures are led by Equipment Problems, followed closely by Design Problems.
5. All the UPS Equipment Problems were caused by failed parts (one of the seven specific cause categories). There was not a clearly distinguishable pattern in the types of equipment failing most often. The failure of UPS batteries appears to be the leading contributor. In many cases, though an internal component such as a Silicon Controlled Rectifier failed, normal power was frequently still available. Therefore, automatic transfer to this source effectively mitigated the impact of the failure.
6. The general root causes for most UPS Design Problems were identified as Inadequate Designs. In many cases, the equipment specified was not compatible with the local environment. For example, an UPS with a 104°F temperature limit was installed by design in a room where the temperature exceeded 100°F on a frequent and prolonged basis. Often no supplemental cooling is included in the design. This may not appear to be a serious design shortcoming, however, the UPS batteries are often rated for only 85°F. Furthermore, the failure rate and lifetime of electronic components are significantly affected by elevated temperatures. The design specifications do not identify the frequency or types of preventive maintenance required for elevated temperatures, and the UPSs are left in a degrading environment without proper attention.

The AEI believes that a detailed UPS failure analysis would likely show that the dominant cause of most UPS failures (identified as Equipment or Design Problems) is tracable to elevated operating temperatures (lack of cooling).

Furthermore, the addition of loads to UPS systems has not been controlled adequately, which has led to overloading. These overload conditions are often indicated by fuses blowing and breakers tripping when normal power is lost. Failure to control "load growth" is considered to be lack of design control, which is often considered to be a design engineering responsibility. This problem can be resolved by implementation of a Configuration Management Program that assures the effects of design changes are appropriately evaluated to assure that equipment is operated within design ratings.

4.3.3 Batteries

The analysis did not reveal a significant number of large centralized battery systems that support several different systems. Unlike commercial nuclear power plants, DOE nuclear facilities tend to have separate battery systems dedicated to supporting specific systems. About half the battery systems for which failure data were reported supported some type of fire

HOW UPS FAILURES WERE FOUND

July 1990 through March 1993

FIGURE 4.4

UPS SUBSYSTEM FAILURES

July 1990 through March 1993

FIGURE 4.5

UPS FAILURE GENERAL ROOT CAUSES

July 1990 through March 1993

FIGURE 4.6

protection system. About a third were for criticality monitors/alarms, followed by various types of other radiation monitoring systems.

Like the analysis for UPSs, the analysis for separate battery systems included all types of service applications for which battery support systems were provided. Failures which had no potential impact on operability were excluded. This screening yielded 52 battery system failures which had occurred over a period of 2-3/4 years.

The results presented below parallel the results presented for EDGs and UPSs.

1. Although the distribution of failures over the period varied somewhat compared to EDGs and UPSs, there was no clearly discernible pattern or reason for further investigation.
2. As shown in Figure 4.7, most battery system failures were discovered during scheduled periodic testing and surveillance, followed by failures which occurred while the equipment was in service. The higher incidence of discovery of failures during testing is attributed to increased battery surveillances introduced in recent years.
3. The general root causes for battery failures are frequently listed as unknown. As shown in Figure 4.8, the known causes of battery system failures are led by two of the nine general cause categories: Design Problems and Equipment Problems.
4. All battery system equipment problems were caused by failed parts (one of the seven specific cause categories). Most often the specific equipment involved either the battery itself or its charger.
5. The majority of the battery system Design Problems involved design inadequacies, followed by a few man-machine interface problems. In several cases, facility systems that were supposed to have been designed with battery-backup power were found not to include this feature, including a glove box fire protection system. In some instances, the capacity of the charger appeared to be inadequate to maintain a sufficient trickle charge on the battery. Occasionally, failures were experienced which indicated that insufficient attention had been given during the design process. One such example was equipment operating in a moisture-laden operating environment, resulting in a short circuit which caused a spurious safety system actuation. In another example, a battery charging circuit associated with a fire protection system failed in a mode that caused the loss of both the normal AC output of the fire protection system and the battery backup for that system. In another case, a "sealed" battery was venting which caused extensive corrosion and failure of adjacent associated electronic components.

HOW BATTERY FAILURES WERE FOUND

July 1990 through March 1993

FIGure 4.7

BATTERY FAILURE GENERAL ROOT CAUSES

July 1990 through March 1993

FIGURE 4.8

4.3.4 Overall Conclusions

Before drawing any overall conclusions from this analysis, it is important to recognize that it is a failure analysis, not a reliability analysis. The factors considered in this analysis do not include the fact that there are thousands of E&BP systems in service throughout DOF nuclear facilities. The total number of surveillance tests that were successful (i.e. did not reveal a failure) and the total number of actual-loss-of-power demands on these systems over the years wherein they performed properly, are not addressed in this analysis. Therefore, it would be inappropriate to draw a conclusion that E&BP systems have excessive failures based on the information provided here. Conversely, during the site visits the AET became aware of a number of E&BP system failures that had not been reported in the ORPS and other failures where the events were not accurately described. Therefore, it should not be assumed that the data analyzed here represent a complete picture of E&BP system performance at DP facilities. The purpose of this analysis is primarily to investigate the cause factors leading to the identified failures.

The analysis considered more than 600 reported failures over a period of 2-3/4 years, through the first quarter of calendar year 1993. The following provides the overall findings and conclusions of the analysis:

1. For all three types of E&BP systems (EDGs, UPSs, and batteries), the majority of the failures involve the batteries and battery chargers. Most battery failures are due to either lack of maintenance (especially preventive maintenance), or the batteries being old and long overdue for replacement. This includes starting batteries for EDGs and the backup batteries in UPSs.
2. For all three types of E&BP systems, the dominant root causes of failures are (1) Equipment Problems (i.e., parts failures), and (2) Designs Problems. In many cases, the causes are "unknown."
3. For EDGs, another frequent cause of system failures involves electrical breakers, often due to improper installation after maintenance or testing. In some cases, the breaker in the normal power system, which was designed to trip upon the loss of normal power, failed to trip due to the failure of the undervoltage trip device.
4. The AET believes that a detailed failure analysis would likely show that the dominant cause of most UPS failures involving failed parts and design problems is traceable to elevated ambient operating temperatures (and lack of supplementary cooling).
5. For UPS systems, another leading trouble area is protective devices (i.e., fuses and circuit breakers). The loads on UPSs typically have not been adequately controlled, which has led to overloading.

5.0 SAFETY SIGNIFICANCE OF EMERGENCY POWER SUPPLY FAILURES

5.1 Safety Analysis Reports

Safety considerations for each nuclear facility are typically summarized in the facility SAR. One purpose of the SAR is to describe the facility response to postulated worst-case (bounding scenario) credible accidents in order to demonstrate that the safety consequences and risk to DOE workers, the public and the environment are acceptable.

The AET reviews of SAR analyses focused on finding the answers to the following questions:

1. Do the SARs assume electric power to be available to support safety functions?
2. Is electric power critical to accomplishment of safety functions?
3. What are the consequences of loss of normal electric power?
4. What are the consequences of loss of normal electric power and single failures within the E&BP system, during both routine process operations and abnormal conditions?
5. What reliability and availability values are assumed for the normal power system and for the emergency or back-up power system?
6. How does actual E&BP supply reliability compare to the values assumed in the SARs?

This process revealed many similarities and some differences among the DOE sites. The results of the AET review of SARs are presented below.

For reactor facilities, postulated accidents described in the SAR typically include loss of off-site electric power. Additionally, FMEAs are often provided that address the consequences of the failure of E&BP supplies to function on demand.

However, most non-reactor nuclear facility SARs reviewed by the AET provided little comprehensive analysis of off-normal conditions, and rarely addressed the safety consequences of events involving loss of power. At one site, SARs did not exist for many facilities. The SARs typically did not address electric power, or would only describe the normal electric power system in qualitative terms, such as "highly reliable," and indicate that emergency loads are supplied from backup sources if normal power is interrupted. In some instances, the SARs did not acknowledge the existence of installed E&BP systems. The SAR accident analysis for one facility at another site only considered loss of power in combination with other events, and the probability of occurrence was declared incredible. Credible single failures of E&BP systems supplying power to equipment relied on to prevent or mitigate the effects of accidents are not analyzed in FMEAs or SAR discussions concerning the facility response to accidents. At some sites,

programs for upgrading SARs in accordance with DOE Order 5480.23, "Nuclear Safety Analysis Reports," have not considered the effects of power losses or single failures of E&BP supplies. The guidance provided with DOE Order 5480.23 describes the need to consider power failures in the accident analysis, as discussed in further detail in Section 6.2 of this report.

There were no FMEAs for many of the non-reactor facilities reviewed by the AET, and the FMEAs that were available did not address the possible failure of EDGs, UPSs, ATSS that switch loads between normal power and emergency power, or other credible single failures. The failure of an ATS to function when normal power has been lost results in loss of access to the backup power source. Although redundant equipment is sometimes provided to help reduce the likelihood of power losses, in most cases the redundant equipment was found to be susceptible to common failure mechanisms. Two examples that were found at multiple sites are: (1) the situation where redundant E&BP sources and redundant equipment are provided (e.g., two EDGs and two pumps with separate local power feeds to the pump motors), but power from the E&BP supplies to the equipment is supplied by common circuits, and (2) the situation where redundant power feeds or circuits are physically supported by a common structure (e.g., utility poles), or are routed through common enclosures.

The SAR analyses reviewed by the AET typically assumed or implied high reliability and availability of E&BP systems, without providing supporting bases. The analyses are frequently weak, out-dated (i.e., do not accurately reflect the existing design and/or processes), and do not address realistic loss of power scenarios. Electric power, whether from normal sources or backup sources, is almost always considered to be available to equipment used to prevent or mitigate the effects of postulated events, maintain safe shutdown, or ensure mission continuity. The E&BP system is assumed to sense the need for backup power when normal power is lost, and to start and/or operate satisfactorily for the duration of the outage (i.e., 100 percent availability and 100 percent reliability). Many of the DOE nuclear facilities reviewed by the AET use a single EDG or UPS system to provide backup power. The AET attempted to calculate the actual reliability of E&BP supplies, but the quality of related performance data (e.g., facility operating logs and maintenance and surveillance records) was poor and would not yield meaningful results (this is further discussed in Chapter 6 of this report). Based on discussions with M&O contractor personnel most knowledgeable concerning E&BP supply performance and failure history, and several crude calculations from the data available, it appears that E&BP supply reliability is fairly good, especially for supplies in more safety significant applications, but most E&BP supplies reviewed by the AET had experienced failures at one time or another.

Specific numeric values for required reliability and availability of E&BP systems are rarely given in the SARs. In a few cases, the reliability of the normal electric power system was quantified in the SARs in terms of failure rate values. These values ranged from 1.2×10^{-2} per hour to 2×10^{-7} per hour, and to 8×10^{-4} per reactor year. In one case, a composite failure value of 7×10^{-8} was given for the normal and emergency power systems. The basis for these values was not provided. In general,

the SARs did not provide analyses to support the assumed reliabilities of the normal or emergency power systems, and M&O contractors were unable to demonstrate the validity of these numbers; the origin of the numbers was usually unknown. As discussed in Section 2 of this report, the review of site load dispatch center logs showed that distribution system power losses affecting one or more facilities are not uncommon. The loss of normal power to a given facility that challenges its E&BP system is clearly a credible occurrence and should be expected. Common causes for loss of normal facility power are inclement weather (rain, snow, sleet, high winds, and lightning), animals (e.g., large birds), and personnel error, often involving movement of heavy equipment (e.g., cranes and trenching/drilling rigs).

Despite the shortcomings cited above, the AETs found the facility SARs to be the best source documents available for assessing the safety significance of E&BP system failures. It was not a question of the analyses being documented elsewhere, but rather that the analyses did not exist or were unavailable to the M&O contractor staff knowledgeable with the facility operations and the SAR. The SARs for reactor facilities and a few newer facilities were found to be considerably better than the average facility SAR described above.

Even though the potential consequences of loss of power events at DOE non-reactor nuclear facilities have generally not been well analyzed, common perceptions among M&O contractor personnel are that (1) a complete loss of electrical power will not result in adverse safety consequences, and (2) that the impact (costs and delays) on DOE programs caused by E&BP supply failures is a larger concern than the potential safety consequences to workers, the public, or the environment. The AET did not find documentation to substantiate these perceptions. The perceptions appear to be based upon general impressions from past experience at given facilities.

At many non-reactor nuclear facilities, the existing fail-safe design features are believed adequate to avoid radiological problems given a complete loss of all power from normal and E&BP sources, assuming no accident has occurred. The potential for contamination of facility personnel from events involving loss of power rarely appeared to concern facility management. The AET was frequently told that the consequences would be limited to the cost and inconvenience associated with mission delays and any building contamination cleanup efforts. The expected consequence of a complete loss of power is that a building may become contaminated, but without a driving force such as an explosion or fire, radioactive materials would be contained within the building. There may be some minor seepage or migration of contamination outside the building, but not to a serious degree. The only critical safety function is to evacuate workers in the immediate vicinity, if necessary. Since radiation and evacuation alarms are usually powered from battery-backed sources, EDG supplied power is often not needed for evacuation, assuming power needs for emergency lighting are provided by UPS or battery systems. However, assuming 100 percent availability of UPS or battery systems can lead to a false sense of security; the AET identified as many, if not more, concerns

with operability (reliability) and maintenance of UPS and battery systems than for EDGs.

Since M&O contractors generally had not analyzed loss-of-power scenarios, the AET attempted to gain an understanding of the potential effects of power losses by (1) reviewing load lists and electrical diagrams to identify specific loads connected to E&BP supplies, and (2) discussing with facility personnel (who were familiar with operations and/or the existing SAR safety analyses) the load functions, basis for providing backup power to the loads, and the consequences and safety significance of load failures.

The AET experienced some difficulty in identifying E&BP supply loads. Load lists and drawings reviewed by the AET were rarely completely accurate. At several sites, the time lag between when modifications are made and the associated drawings are updated is excessive (often huge backlogs exist), and therefore the latest version of drawings are often outdated and do not accurately reflect the existing designs. The best available information was often uncontrolled drawings that had been marked up by facility engineers to reflect the existing configuration to the best of their knowledge. The accuracy of as-built drawings was identified as a deficiency at practically all sites. The drawings at several facilities were described as useless for working on modifications. At many facilities, walk-down reviews (i.e., tracing the existing circuits by hand to determine the exact electrical system configuration) are conducted as routine practice before proceeding with new work. Although necessary where accurate drawings are not available, this is usually a very time consuming process that is difficult to perform without errors. Configuration management problems concerning inaccurate drawings were well recognized by facility staff.

The following loads were generally considered by the AET and facility staff to be the most important loads receiving backup power from EDG, UPS, or battery systems in terms of protecting workers, the public, or the environment. These loads were typical to most non-reactor nuclear facilities:

- Ventilation system equipment (in particular, exhaust fans and related controls);
- vacuum pump/blower motors associated with local room air monitors that detect airborne contamination;
- emergency lighting;
- radiation monitoring instrumentation (e.g., continuous air monitors, tritium monitors, etc.);
- facility communication/notification systems;
- alarm systems (radiation and fire); and
- stack monitoring instrumentation.

At some non-reactor nuclear facilities, E&BP is not considered critical to the safety of workers, the public, or the environment. The worst case effect of loss of power is that workers would be "caught in the dark" and have to "feel their way out" of the facility. For one such facility, radiation monitors that are supplied backup power from an UPS were considered important to worker safety, but work in the affected area is not allowed if the monitors or UPS are inoperable. An event involving loss of normal and backup power and requiring the need for radiation detection was considered to be a very low probability event, and therefore not a concern. It was clear to the AET that facility staff often believed that scenarios involving a breach of confinement (e.g., glovebox) and a resultant spill would not involve a loss of electric power. Most of these facilities had experienced power losses. At a number of facilities, the AET was told that it was not uncommon to loose power several times a year.

At a few facilities, operations are allowed to continue following loss of the normal power source if backup power is available. However, the more common practice at facilities reviewed by the AET was to stop processes/operations when normal power is lost, regardless of whether backup power is available from E&BP sources. Because the ventilation system is key to worker protection at many nuclear facilities, processing activity is not allowed if the number of power sources available to ventilation system equipment has been reduced. Some facilities are evacuated if power is lost to the ventilation system. The ventilation system is designed such that building air flows are from areas of lesser contamination potential to areas of increasingly greater contamination potential. The typical ventilation system air flow path is from outside the facility to general areas (e.g., offices, lunch rooms, hallways, etc.), then to laboratory areas, then to glovebox or other confinement areas where processing occurs within the laboratories, and finally to filters that remove contamination prior to discharge outside the building. The ventilation system exhaust fans are typically relied upon to help maintain correct differential pressures and flow patterns between these various areas to ensure proper air flow. Buildings are evacuated as a precaution when the ventilation system is inoperable because of the increased potential for airborne contamination, and the reduced air flow past room radiation monitors. Ventilation systems are often designed with fail-safe features. Supply dampers automatically close on loss of power to prevent backflows (in some designs, compressed air stored in accumulators is used as the motive force to close dampers), and high-inertia fan pulleys are used to prolong coast down time to maintain air flows in the proper directions for a short time following loss of power to the fan motors. At one facility, one of two EDGs was required to start within one minute following loss of normal power because exhaust ventilation flow was needed to mitigate the consequences of some accident scenarios. For this facility, if normal power is lost and backup power is provided by the EDGs, then processing is stopped, all non-essential personnel leave the processing areas, and the process rooms are closely monitored to ensure that the ventilation system continues to provide proper air flows. Efforts are then concentrated on how to restore power. If EDG power is also unavailable, the building is evacuated.

Building evacuation on loss of power was often credited for ensuring that workers were not exposed to undue risk. Facility systems or equipment is considered necessary only if needed for evacuation, such as radiation detection and alarm systems and emergency notification systems. It appeared to the AET that emergency lighting should also be included in this category, but appeared to be sometimes overlooked.

The SAR for one facility stated that the purpose of the emergency power system is to retain all normal barriers and contingencies against the migration or release of radioactive materials, to maintain the capability to detect, alarm, control and mitigate events, to ensure the safety of on-site and off-site personnel, and to sustain adequate safeguards and security for the facility. At several facilities, the AET was told that loss of power procedures required personnel action to ensure the facility is in a safe condition (e.g., verifying that appropriate valves are closed, tank levels are correct and stable, making sure there are no spills and that systems are in a safe state, etc.). At another facility, the security force was required to enter the facility and take actions following power losses. In some cases, personnel responding to power losses are required to wear respirators. For one facility that was said to always be evacuated upon loss of normal power, the procedure for loss of power was very general, stating to "take immediate action to protect personnel, the environment, and equipment," to monitor the area for any unusual conditions using the appropriate respirator and safety equipment, and to restart the ventilation system when power is restored. The procedure does not discuss building evacuation or potential hazards associated with loss of power.

At several facilities it was indicated that a portable EDG unit could be brought in and connected to supply facility loads if the dedicated EDG(s) failed to start. A few facilities had junction boxes that allowed easy hookup capability for this purpose. The length of time required to realistically expect EDG power from a portable unit varied from within an hour or two up to a day, depending on a number of factors such as location and availability of units, ease of connection, etc. In general, it did not appear credible to rely on portable units for successful mitigation of accidents following failures of dedicated (i.e., permanently installed) units.

For some non-reactor nuclear facilities, the only safety system considered critical is the building structure itself. The buildings are considered critical because if interior confinement is compromised, the building is relied on to contain any contamination. It was generally felt that a building could easily be evacuated following loss of ventilation in time to protect the health and safety of workers. These buildings were generally designed to withstand seismic events. The E&BP supplies within the buildings often did not appear to be seismically qualified themselves. The UPSs were often freestanding instead of secured to the facility structure, and batteries were not secured to their racks. Some racks appeared not to be seismically designed. The SAR analysis of at least one facility assumed the availability of electric power following a design basis earthquake.

Although SARs frequently contained information which implied that electric power is necessary to accomplish some safety functions, it was often not clear to the AET whether electric power is actually needed to ensure facility safety. In many cases it was clear that the availability of electric power is preferred, and usually results in less complicated events with fewer safety implications. A detailed analysis of credible loss of power events may reveal either that E&BP is not needed for safety reasons, or that the safety of workers, the public, or the environment can only be assured if power remains available to critical systems. At one facility, the AET identified a loss of power scenario that appeared to have the potential for a release that was not evaluated for risk or safety significance.

The AET believes that current SARs need to be upgraded to include analysis of loss of power situations (with and without accidents). There appears to be a need to carefully analyze "stagnant" building conditions resulting from a loss of all AC power, without an accident, to confirm whether the safety consequences are acceptable. In addition, scenarios involving the complete loss of AC power in conjunction with postulated worst-case credible accidents (e.g., seismic events) should be analyzed to determine whether their probability of occurrence is low enough to be considered incredible, and therefore, beyond the design basis for the facility; or alternatively, that the facility design is adequate to limit the safety consequences to workers, the public, and the environment to acceptable levels. The analyses and results should be carefully documented and should form the design basis for safe facility operation. Many DOE facilities are currently in the midst of SAR upgrade programs which should result in improved accident analyses. The safety significance of E&BP supplies needs to be fully understood so that those supplies and loads important to safety are identified, classified, recognized, and treated as such by designers, users, and maintainers.

The AET recommends that a formal analysis of loss of normal facility power in conjunction with single failures within the emergency/backup power system be considered for Nuclear Hazard Category 1 and 2 Facilities (as defined in DOE Standard 1027-92, "Hazard Categorization and Accident Analysis Techniques for Compliance with DOE Order 5480.23, Nuclear Safety Analysis Reports"). This loss of power analysis should address the probability and consequences of E&BP system failures and should identify equipment and personnel actions necessary to ensure the protection of workers, the public, and the environment. The analysis should identify E&BP system equipment important to safety so that the equipment is included in appropriate programs (e.g., maintenance & surveillance, work authorization, change control, drawing control, etc.) to ensure reliable accomplishment of safety functions. The analysis results should be formally documented and updated as necessary to reflect current facility hazards and the E&BP system configuration.

The following sections provide guidance from DOE Orders and an Occupational Safety and Health Administration (OSHA) Standard regarding recommended safety analysis techniques, and address specific considerations in determining the safety significance of individual E&BP supplies.

5.2 Guidance in DOE Orders on E&BP Supplies

Attachment 1 "Interim Guidance for DOE Order 5480.23" to DOE Order 5480.23 "Nuclear Safety Analysis Reports" states that a SAR is a risk management tool that will define the basis for safety and risk acceptance for the facility or operation. The SAR includes the operating envelope defined by TSRs, safety design bases, commitments to applicable codes and standards, facility management controls, and institutional and human factors safety provisions. As discussed in further detail below, the safety basis established by the SAR safety analysis shall include the various design and programmatic characteristics necessary to protect workers, the public, and the environment from facility hazards. The safety analysis should consider a range of normal, abnormal, and accident conditions. Equipment failures, active and passive, should be considered to determine whether the design is such that safety is unduly dependent on specific pieces of equipment (e.g., E&BP supplies) or personnel actions (e.g., actions required to ensure safety following E&BP system failures).

The DOE ES&H Policy dated June 1993 states:

"The hallmark and highest priority of all our activities is daily excellence in the protection of the worker, the public, and the environment."

This policy is the result of a DOE initiative for a comprehensive safety and health policy that clearly establishes the responsibility of DOE and its contractors to protect the health and safety of workers "inside the fence." The policy further states that DOE will use innovative and effective approaches to risk identification and management, and apply a systematic approach to all activities that affect ES&H. In order to effectively implement this policy, facility hazards and the importance of equipment (including E&BP supplies) relied on to protect workers, the public, and the environment from the hazards must be clearly and accurately understood and documented. This is essential to ensure that facility equipment is operated and maintained in a manner to adequately manage and control the risk posed by the hazards.

Despite the known potential for challenges to E&BP system equipment, M&O contractors were usually unable to provide the AET with documentation or analyses concerning the safety significance of E&BP supplies. The safety implications of E&BP supplies at DOE facilities and their contributions to overall risk are not well analyzed and do not appear to be fully understood. The analysis and understanding of the potential effects and the importance of E&BP equipment failures are necessary to (1) comply with the DOE ES&H policy stated above, (2) to ensure the proper graded approach implementation of DOE Orders, and (3) to ensure the equipment is properly classified, maintained, and included in appropriate programs to ensure adequate performance and reliability.

The DOE Orders discussed in this section are to be implemented using a "graded approach." This means that the extent and level of detail of safety analyses required to demonstrate compliance with ES&H requirements will vary

among facilities depending on considerations such as the hazards and risks involved, and the size and complexity of facility processes, systems, and equipment important to safety.

The stated purpose of DOE Order 5480.23, "Nuclear Safety Analysis Reports," is:

"...to develop safety analyses that establish and evaluate the adequacy of the safety bases of the facilities. The Nuclear Safety Analysis Report (SAR) required by this Order documents the results of the safety analysis." The Order further states that "DOE nuclear facilities shall be required to perform a safety analysis that develops and evaluates the adequacy of the safety basis for each such facility. The safety basis to be analyzed shall include management, design, construction, operation, and engineering characteristics necessary to protect the public, workers, and the environment from the safety and health hazards posed by the nuclear facility or nonfacility operations."

The Order states the following regarding the scope and content of safety analysis reports:

1. *SARs shall define the safety basis, document the logic of its derivation, demonstrate adherence to the safety basis, and justify its adequacy.*
2. *Each SAR required by this Order shall include thorough documentation of the assumptions employed in the safety analysis.*
3. *A SAR shall include the results of the safety analysis that identifies the dominant contributors to the risk of the facility so that these vulnerabilities can be better managed.*

Topics listed which the Order states that the safety analysis shall address include:

- Applicable statutes, rules, regulations, and Departmental Orders; and applicable facility design codes and standards;
- Facility description and operation, including design of principal structures, components, all systems, engineered safety features, and processes; and hazard analysis and classification of the facility;
- Analysis of normal, abnormal, and accident conditions, including design basis accidents; assessment of risks; consideration of natural and man-made external events; assessment of contributory and causal events, mechanisms, and phenomena; and evaluation of the need for an analysis of beyond-design-basis accidents; and
- Derivation of TSRs.

Attachment 1 to DOE Order 5480.23 provides "Interim Guidance for DOE Order 5480.23." Section 4.f.(2) describes the above features that must be present

in SARs. Item (d) of this section provides guidance on how to "Justify the Adequacy of the Safety Basis in Protecting the Health and Safety of the Public and Workers and the Environment;" (d)1 states in part that:

"The safety analysis should consider a range of conditions, including normal releases, abnormal, accident, and design basis accident, in order to test the adequacy of the protection afforded by commitments to the safety basis," and (d)2 states that "Failure mechanisms that should be considered in exploring that vulnerabilities of DOE nuclear facilities or operations to accidents include equipment failures (active and passive), external disturbances (e.g., earthquakes, storms, floods, volcanism, transportation accidents, explosions or accidents at neighboring facilities, etc.), human error (errors in operations, maintenance, or surveillance testing), and institutional controls (improper staffing, inadequate availability of essential utilities and functions such as electrical power or emergency response teams, breakdown of quality control, problems with qualification of spare parts, etc.)."

Section 4.f.(3).(d).11, "Analysis of Normal, Abnormal, and Accident Conditions, Including Design Basis Accidents," paragraphs (l) and (m) state in part that

"Accident analyses should include the derivation and documentation of measures of importance-to-risk or importance-to-safety as applied to a hierarchy of safety provisions (defense in depth). The hierarchy should identify the importance of safety functions," and "Failure modes of equipment or personnel found to be particularly "important to safety" must be examined to determine whether the safety of the facility is unduly dependent upon such components or personnel actions. The allocation of safety functions may require modification to reduce the importance-to-safety of critical links in the assurance of safety....Consideration must be given to employing additional levels of assurance, diversity, or redundancy to avoid placing undue reliance on any one safety device or personnel action."

Therefore, the facility response to analyzed events should consider single failures of E&BP system equipment, including EDGs and ATSS. If the analysis shows that equipment failure could have a potential adverse impact on the safety of workers, the public, or the environment, the equipment should then become part of the facility configuration management program, i.e., the design requirements and design basis for the equipment should be formally established, documented, and maintained. The basic elements of a configuration management program are discussed in draft Standard DOE-STD-CM-XX, entitled, "Implementation Guide for Operational Configuration Management Programs, Including the Adjunct Programs of Design Reconstitution and Material Condition and Aging Management," dated May 1993. The configuration management program includes the identification and control of changes that could affect equipment important to safety, and control of documents containing design requirements and design basis information, including as-built drawings that accurately reflect the installed design. The goal of a configuration management program is to maintain consistency between the

design requirements, the facility physical configuration, and associated documents. Similar to upgrades of SAR safety analyses, the configuration management program should be implemented using a graded approach.

The guidance provided in DOE Order 5480.23 is generally consistent with an OSHA Standard, "Process Safety Management of Highly Hazardous Chemicals," published in the Code of Federal Regulations (CFR), specifically, 29 CFR 1910.119. Although concerned with chemical hazards as opposed to nuclear hazards, the methodology for ensuring worker safety is basically the same. The purpose of the OSHA Standard is to provide requirements for preventing or minimizing the consequences of releases of toxic, reactive, flammable, or explosive materials that present serious danger to employees in the workplace. The term "process" means any activity involving a highly hazardous chemical including any use, storage, manufacturing, handling, or the on-site movement of such chemicals, or combination of these activities.

Discussion from Appendix C to 29 CFR 1910.119, "Compliance Guidelines and Recommendations for Process Safety Management (Nonmandatory)," states that the major objective of process safety management is to prevent unwanted releases of hazardous chemicals, especially into locations that could expose employees and others to serious hazards. An effective process safety management program requires a systematic approach to evaluating the whole process. Using this approach, the process design, process technology, operational and maintenance activities and procedures, nonroutine activities and procedures, emergency preparedness plans and procedures, training programs, and other elements which impact the process are all considered in the evaluation. The various lines of defense that have been incorporated into the design and operation of the process to prevent or mitigate the release of hazardous chemicals need to be evaluated and strengthened to ensure their effectiveness at each level. Process safety management is the proactive identification, evaluation, and mitigation or prevention of chemical releases that could occur as a result of failures in process, procedures, or equipment. The process safety management standard targets highly hazardous chemicals that have the potential to cause a catastrophic incident. The purpose of the standard is to aid employers in their efforts to prevent or mitigate episodic chemical releases that could lead to a catastrophe in the workplace.

The compilation of written process safety information is required to enable the employer and employees involved in operating the process to identify and understand the hazards posed by highly hazardous chemicals. The following three categories of information are required: (1) information pertaining to the hazards involved - toxicity information, permissible exposure limits, physical data, reactivity data, corrosivity data, thermal and chemical stability, hazardous effects of inadvertent mixing of different materials that could foreseeably occur, etc., (2) information pertaining to the process technology - flow and block diagrams, process chemistry, maximum intended inventory, safe upper and lower limits for process variables such as temperatures, pressures, flows, etc., an evaluation of the consequences of deviations, including those affecting the safety and health of employees, and (3) information pertaining to process equipment - materials of construction, piping and instrumentation diagrams (P&IDs), electrical

classification, relief system design and design basis, ventilation system design, design codes and standards employed, material and energy balances, and safety systems (e.g., interlocks, and detection or suppression systems). The employer shall document that safety system equipment complies with recognized and generally accepted good engineering practices, and is designed, maintained, inspected, tested, and operated in a safe manner.

A Process Hazard Analysis (PHA) is required, using acceptable analysis methodologies, appropriate to the complexity of the process that identifies, evaluates, and controls the hazards involved in the process. The process hazard analysis shall address the hazards of the process, any previous incident which had a likely potential for catastrophic consequences in the workplace, engineering and administrative controls applicable to the hazards and their interrelationships such as appropriate application of detection methodologies to provide early warning of releases, consequences of failure of engineering and administrative controls, human factors, and a qualitative evaluation of a range of the possible safety and health effects of failure of controls on employees in the workplace. The process hazard analysis is to be periodically updated to ensure it is consistent with the current process.

Discussion from Appendix C to 29 CFR 1910.119, "Compliance Guidelines and Recommendations for Process Safety Management (Nonmandatory)," states that a PHA is an organized and systematic effort to identify and analyze the significance of potential hazards associated with the processing or handling of highly hazardous chemicals. A PHA provides information which will assist employers and employees in making decisions for improving safety and reducing the consequences of unwanted or unplanned releases of hazardous chemicals. A PHA is directed toward analyzing potential causes and consequences of fires, explosions, releases of toxic or flammable chemicals and major spills of hazardous chemicals. The PHA focuses on equipment, instrumentation, utilities, human actions (routine and nonroutine), and external factors that might impact the process. These considerations assist in determining the hazards and potential failure points or failure modes in a process.

The AET performed a search of DOE Orders to find other guidance, requirements, or references relevant to electrical power and E&BP systems or equipment. The following excerpts from DOE Order 5480.22, "Technical Safety Requirements," directly relate to facility-specific safety analyses as discussed above.

DOE Order 5480.22 gives the following definition for TSRs:

"Technical Safety Requirements (TSRs) means those requirements that define the conditions, safe boundaries, and the management or administrative controls necessary to ensure the safe operation of a nuclear facility and to reduce the potential risk to the public and facility workers from uncontrolled releases of radioactive materials or from radiation exposures due to inadvertent criticality. A TSR consists of safety limits, operating limits, surveillance requirements,

administrative controls, use and application instructions, and the basis thereof."

Section 7 "POLICY" of DOE Order 5480.22 states the following:

"It is the policy of the Department that nuclear facilities operate within PSO-approved TSRs which prescribe the bounds for safe operation of these facilities in order to protect the health and safety of the public and reduce risk to workers."

Attachment 1, "Guidelines for Technical Safety Requirements," to DOE Order 5480.22 states in part that: (1) TSRs should be derived from site specific safety analyses which consider all credible accidents, (2) that operation within the bounds of the TSRs provide reasonable assurance that the nuclear facility will not threaten the health and safety of the public or pose an undue risk to workers from uncontrolled releases of radioactive or other hazardous materials, and (3) that in order to serve as the basis for the TSRs, the safety analyses or other documents must systematically evaluate all potential off-normal conditions that are expected to occur during the life of the facility. Section II.2.3.h of Attachment 1 describes the content of TSR Limiting Conditions for Operation (LCOs) for non-reactor nuclear facility systems and equipment. This section states that the TSRs should include structures, systems, and components that are relied upon in the Safety Analyses to function or actuate to prevent or mitigate accidents or transients that involve the assumed failure of physical barriers designed to prevent radioactive releases (i.e., TSRs should include equipment assumed to successfully operate to ensure the resulting consequences are acceptable, including instrumentation used to detect and indicate the condition). This section further states that the TSRs should also include:

"...systems that automatically place the facility in a safe condition, such as instrumentation and controls that trip or slow processes and automatic isolation systems. Other items that might be included, if they are assumed by the Safety Analyses to operate, are emergency power sources (diesel generators, turbines, etc.), fire detection/suppression, and possibly seismic detection instrumentation. Containment/confinement requirements would be included. In all cases, support and actuation systems necessary for the above to function must be included, such as instrumentation and controls, power supplies (electric, compressed air), and cooling systems."

Therefore, the safety analyses should also identify E&BP supplies relied upon to reduce the risk to the public and to workers from radiological hazards for the purpose of establishing appropriate TSRs².

² Attachment 1 to DOE Order 5480.22 acknowledges that although TSRs reduce the risk to workers and facilities, it is impractical and not intended for TSRs to reduce risk to insignificant levels. The protection of workers is assured through a combination of equipment (e.g., alarms and protective clothing) and programs (e.g., training), of which TSRs are a part.

Other guidance, requirements, or references in DOE Orders relevant to electrical power and E&BP systems or equipment identified by the AET concern specific types of applications that require power from E&BP sources. The following excerpts are from DOE Order 6430.1A, "General Design Criteria," which provides requirements for the design of DOE facilities.

- Safety class items of ventilation systems installed on enclosures (i.e., physical barriers such as gloveboxes, fume hoods, etc. that along with the ventilation and operating systems prevent the release of radioactive or other hazardous materials to the work space or environment) shall be supplied with emergency power [Section 1161-4].
- Where non-reactor nuclear facility confinement ventilation systems are required to provide controlled continuous confinement airflow, the associated electrical equipment and components shall be supplied with safety class electric power and provided with an emergency source [Section 1550-99.0.2].
- For facilities that process plutonium or enriched uranium, a safety analysis shall establish the minimum acceptable performance requirements for the ventilation system and the response requirements of system components, instrumentation, and controls under normal operations, anticipated operational occurrences, and design basis accident conditions. The safety analysis shall determine system requirements such as the need for redundant components, emergency power for fans, dampers, special filters, and fail-safe valve and damper positions. Ventilation system components and controls that require electric power to perform safety functions shall be supplied with a safety class UPS and/or emergency power supply as is determined to be required by a systems design/safety analysis [Section 1550-99.0.2].
- The design of fire protection systems for non-reactor nuclear facilities shall include an emergency source of electric power to operate the systems. Fire protection systems shall be capable of operating during a normal power outage. The emergency power sources and the electrical distribution circuits shall have independence and testability to ensure performance of their safety functions assuming any single failure [Section 1530-99.0].
- Design features for uranium enrichment facilities are to include standby power that shall be provided automatically on loss of normal power. The standby power system shall be safety class and capable of providing continuous power for the time required to achieve a safe shutdown condition or for the period of time that components require power to perform their necessary safety functions, whichever is greater. The electric power generating capacity shall be the sum of all emergency power loads and provide adequate reserve capacity for future loads. The inductive loads from equipment startup, such as induction motor starts, shall be considered in the standby power system design [Section 1318-4.1].

- General requirements³ are that standby and emergency electrical systems be provided to serve loads set forth in NFPA 110 "Standard for Emergency and Standby Power Systems." Additional standby or emergency systems shall be provided to support systems or equipment components whose operating continuity is determined to be vital for protection of health, life, property, and safeguards and security systems. Uninterruptible power shall be provided for equipment that cannot sustain functions through the momentary power loss that occurs when an alternate power source comes on line and picks up load. Emergency power shall be provided for protective alarm and communications systems as dictated by the systems requirements. Switchover to emergency power shall be automatic on failure of the primary power source and shall be indicated on an annunciator panel. The annunciator shall be located in an occupied area and shall indicate any problems with the emergency system. Emergency power shall service essential fire alarm, security alarm, and supervisory sensing devices. Emergency power equipment areas shall be ventilated to maintain satisfactory ambient temperatures for equipment operation and personnel access [Section 1660-1].
- Sites or facilities requiring continuous exterior lighting for safety or security reasons shall have an emergency power source for such lighting [Section 1630-3.2].

Other DOE Orders that contain information regarding E&BP system applications include DOE Order 5632.2A, "Physical Protection of Special Nuclear Material and Vital Equipment," which addresses emergency backup power for security systems, and DOE Order 5820.2A, "Radioactive Waste Management," which addresses backup power requirements for high level waste monitoring and leak detection devices.

5.3 Guidance for Assessing the Impact and Safety Significance of Loss of Power

Many factors must be considered in understanding the significance of E&BP system failures within the DOE complex. The applications of E&BP supplies (installation designs and load functions) and the need for emergency electric power differ greatly from facility to facility. Additionally, since many facilities are dynamic in nature (i.e., mission requirements dictate that the processes and hazards frequently change over the years), the requirements related to E&BP sources similarly change. The AETs concentrated on E&BP supplies used in more safety significant applications (e.g., providing back-up power to moderate or high-hazard facilities such as reactors or plutonium, uranium, or tritium processing or storage facilities). At reactor facilities, backup power from E&BP systems is used

³ Additional requirements for safety class emergency electrical systems for non-reactor nuclear facilities are provided in Section 1660-99.0 of DOE Order 6430.1A. Electric power and electrical instrumentation and control systems are designated safety class if they are required to satisfy the safety class criteria in Sections 1300-3.1 through 1300-3.4 of the Order.

to support both decay heat removal and accident mitigation systems. At non-reactor nuclear facilities, the primary safety functions using back-up power are building ventilation and confinement systems, and alarms relied on to ensure the safety of facility workers.

Emergency power systems are complex. The systems are generally required to either sit dormant for long periods of time (e.g., EDGs), or serve in a standby capacity where they are not being challenged (e.g., batteries, including those in UPS applications), and then accurately and dependably sense a loss of power and transfer large amounts of energy to connected loads, sometimes under adverse conditions. The electro-mechanical (or in the case of battery systems, electro-chemical), nature of the devices makes them particularly sensitive to the quality of maintenance programs. In addition, institutional deficiencies such as a lack of configuration control (e.g., unanalyzed or uncontrolled addition of electrical loads) can result in degraded reliability of emergency power systems.

Some safety system functions can be accomplished without electric power. The system designs typically rely upon gravity, natural circulation flow, or "fail-safe" features. Examples include: reactor emergency shutdown system designs in which the fail-safe design of the rod holding mechanisms allow the safety rods to automatically insert by the force of gravity upon loss of electric power; coolant pumps with large inertia flywheels that prolong coast down time following loss of power to the pump motors to maintain flow and initiate natural circulation cooling; and safety-related ventilation system designs in which supply and exhaust dampers go to safe positions upon loss of electric power. However, for facilities where follow-up mitigation functions are necessary (i.e., beyond immediate shutdown or cooling needs), the systems performing those functions usually require electric power.

In some cases, continuously operating on-line diesel generators are provided to guard against loss of pumping power in a decay heat removal system or to guard against loss of fan power in a confinement/ventilation system. Such design features are not typical in the commercial nuclear industry. In a few cases, other non-electrical backup power sources (e.g., steam) are provided in the facility/site design to power cooling or ventilation systems. In one facility design, normal power is backed up by a redundant pair of steam supply lines, which in turn are backed up by a standby EDG system. In such a case, when the availability of normal power and the availability of the two backup steam systems to operate steam turbine driven pumps are considered, the reliability and availability of the backup EDG system appear to be not as critical.

The reliability required of a given E&BP supply depends on its design basis application. If the supply is the only backup to a single normal power line and E&BP is required to ensure safety, then a single E&BP source might not be considered adequate, even if it has demonstrated high reliability. In contrast, if the supply is the backup to a diverse source (e.g., steam powered equipment) which is in turn the backup to two sources of normal electric power, then a lower reliability might not be a concern. The E&BP supply would then be the third or fourth level system available to provide the motive force for safety functions. The requirements for availability of

EDG, UPS, or battery power, or some combination of these, depends upon the nature of the facility process and the response to postulated accidents. A successful automatic start of an EDG within ten seconds might be required in some cases to ensure safety, and in other cases a manual EDG start within an hour might be sufficient. The hazard might be such that there would be no safety consequences even if the EDG fails to start.

To ascertain the safety significance of any single E&BP supply requires consideration of the need for electric power for safe shutdown of the facility and for prevention or mitigation of credible accidents (to ensure the health and safety of workers, the public, and protection of the environment). The potential failure consequences of E&BP supplies must be fully understood to determine their safety significance. E&BP supply failure consequences should be assessed in two parts: first is the case where power is lost during routine plant operations (i.e., with no abnormal conditions such as transients or accidents), and second is the case where loss of normal power occurs in conjunction with credible transients or accidents. The E&BP system design configuration must also be considered (e.g., whether redundant E&BP supplies are provided or if diverse means for accomplishing safety functions are included in the design). Additionally, for applications with multiple EDGs, the loss of all normal AC power and all EDG backup AC power (for non-accident conditions only) should be considered. This scenario is often referred to as a "blackout" in that all sources of AC electric power are assumed to be lost. Only battery-powered sources are assumed to remain available. The blackout scenario is considered a credible event and is analyzed for commercial nuclear facilities. The AET believes the blackout scenario should also be analyzed for DOE nuclear facilities. Power system reliability is thought to be better for commercial nuclear facilities, in part due to more redundancy and better maintenance of E&BP equipment. However, this may be more than offset by the simpler applications of E&BP equipment in DOE non-reactor nuclear applications, and the less significant accident consequences (i.e., lower source term).

The bounding worst case (limiting) accident scenarios should be analyzed for each facility to determine whether the scenarios are credible (i.e., have a realistic potential for occurring during the lifetime of the facility), and for those scenarios that are determined to be credible, determine whether the consequences with respect to ES&H are acceptable (i.e., either negligible, or prevented or mitigated by facility safety systems and/or administrative controls). The role and safety significance of E&BP supplies in preserving facility safety needs to be analyzed and fully understood so that those supplies important to safety are identified, classified, recognized, and treated as such by designers, users, and maintainers. The need for TSR LCOs on E&BP supplies will depend on the analysis results. The results of the analysis should be carefully documented so that the design basis and safety significance of E&BP supplies can be clearly demonstrated and understood. This level of documentation is necessary to ensure proper control of changes affecting E&BP equipment, for developing adequate procedures for operation and maintenance, and to demonstrate compliance with DOE Orders and regulations.

A loss of power analysis to determine the safety significance of an E&BP source (e.g., generator, UPS, or battery) would typically, as a minimum, involve the following steps:

1. Identify and list all loads receiving power from the backup source. For many E&BP supply applications this step may be one of the most difficult in the analysis since assigned loads are added and/or deleted over the years, often without accurate records. The AET found that although the major loads powered from E&BP sources could usually be identified, the exact connected loads were often unknown for E&BP supplies at many facilities.
2. List the functions of each system or load receiving power from the backup source, and determine which load functions are important to the safety of workers, the public, or the environment.
3. Determine the basis for providing backup power to each load (e.g., to ensure worker safety, prevent releases to the environment, prevent loss of valuable data, maintain production capability, etc.), and whether providing backup power is really necessary. Where it is determined that provision of power to loads that help ensure the protection of workers, the public, or the environment is not necessary, the alternate provisions that ensure protection should be identified. The reliance of the alternate means on backup power and susceptibility to common failures should be addressed.
4. Assess the safety significance of failure of the backup power supply to provide power as designed upon loss of the normal power source. The total combined effect of loss/failure of all connected loads simultaneously should be analyzed unless there is a clear reasonable documented basis for excluding certain loads. The analysis should take into consideration the following aspects:
 - Procedural reliance on the availability of power. The effect of the unavailability of power on performing procedural steps is often not immediately obvious. Procedures may call for operator actions that rely on availability of equipment that is no longer available, or require lighting that may no longer be available (e.g., the procedural response to loss of power may be to read local instruments to ensure process safety, but there may not be adequate lighting in the area to take the readings due to the power loss). Procedures are often written taking the availability of power for granted.
 - The affects of cascading power losses should be considered. If power is lost to a main or upper level bus or motor control center, then the effect of loss of power to all loads that receive power from downstream connected buses, distribution panels, and load centers should be evaluated. Different alignments that may be used should be considered to ensure all potential configurations are adequately analyzed. A common pitfall is to assume power remains available where an ATS or similar device is used to supply power to

loads from either of two separate sources. Problems with such an assumption include: (1) loss of power to critical loads can often be caused by failure of the transfer device itself, even if the E&BP supply functions as designed; therefore, ATS failures should also be considered, (2) a downstream bus fault could result in loss of power to all loads regardless of the number of available sources of power to the bus via ATS devices or other means, and (3) the AET often found single failure vulnerabilities between redundant or separate feeds into ATS devices, i.e., the redundant sources of power shared some common element such that they were not truly independent from each other. The ATS devices often provide a false sense of security; while they generally improve the availability of the system, they also introduce another failure mechanism by which neither source of power is available.

- In addition to safety, there may be additional reasons for treating an E&BP source as if it were important to safety (i.e., in terms of its classification, preventive maintenance activities, etc), such as:

- a. Mission impact; for example if the loss of power could potentially result in unnecessary or excessive costs or delays.
- b. Avoiding unnecessary or excessive challenges to the facility safety basis, and to equipment important to safety. Although analysis might demonstrate that facility safety can be maintained without the need for electrical power, it would appear desirable to try to ensure the operability of an E&BP source if its availability results in a less complicated event with fewer safety implications. For example, if the loss of power would require facility evacuation or other actions that could be perceived as a last resort because of nuclear hazards, it would appear desirable to ensure the availability of power to avoid potential negative publicity and associated audits and investigations that often result in today's regulatory environment.

5. Carefully and accurately document the results of the above analysis so that the safety significance of the E&BP supply can be demonstrated, and actions taken relative to its importance can be justified. The analysis results should be revised as necessary to account for changes in E&BP supply loads or applications.
6. Treat the E&BP supply accordingly. The requirements in DOE Orders regarding maintenance activities, etc. should be applied using a graded approach based on the safety significance of the supply. If the E&BP source is important to safety, then actions should be taken to provide a high degree of assurance that it will operate as designed when needed. For E&BP equipment determined to be important to safety, aspects to consider for ensuring reliable operation include:

- proper equipment classification;

- acceptance criteria for surveillance tests, post-maintenance testing, and preventive maintenance activities;
- equipment performance monitoring and trending program;
- inclusion in quality assurance program;
- inclusion in work control process (systematic approach to control of activities);
- inclusion in configuration management program (control of design requirements and associated documents, and control of system changes);
- training of maintenance and operations personnel; and
- records management and document control (e.g., for test data, SAR description and safety analysis, TSRs where necessary, vendor manuals, drawings, etc.).

The AET believes that loss-of-power analyses should be performed for E&BP systems that support Nuclear Hazard Category 1 and 2 Facilities (as defined in DOE Standard 1027-92 "Hazard Categorization and Accident Analysis Techniques for Compliance with DOE Order 5480.23, Nuclear Safety Analysis Reports"). The level of detail required and magnitude of resources expended for the analysis would be determined using a graded approach (i.e., would be commensurate with a facility's relative importance to safety, environmental compliance, safeguards and security, programmatic significance, and/or other facility-specific requirements). Thorough and well documented analyses that clearly identify the safety significance of E&BP systems and the consequences of failure should prove cost beneficial in the long term by: (1) making subsequent facility modifications easier to analyze, design and implement, (2) saving resources on subsequent DOE initiatives such as SAR upgrades and configuration management programs since part of this work will have been done through the analysis, (3) forming the basis for demonstrating facility safety and justifying operations to DOE, and (4) reducing the burden on maintenance resources by properly identifying equipment that is not important to safety or mission objectives.

6.0 STANDBY/EMERGENCY POWER SUPPLY MAINTENANCE & TESTING

The PM programs established to ensure that test, inspection, and routine maintenance activities (i.e., monitoring, adjusting, cleaning, etc.) are performed in a prescribed manner and at periodic intervals are essential to ensuring that E&BP equipment is maintained in an optimal condition for adequately responding to loss of power demands. Much of the E&BP equipment at DOE sites remains in a non-operational or "standby" mode for the majority of its installed life. Therefore, the PM programs take on added importance for ensuring the operability and capability of E&BP equipment to accomplish design basis mission and safety functions.

Areas of excellence in maintenance of electrical equipment were noted at all DOE sites that participated in the AET review. The AET was impressed with the positive attitude of personnel responsible for performing PM on E&BP system equipment. They were knowledgeable of their systems and concerned with the quality of work performed. There appeared to be a genuine interest in maintaining the reliability of E&BP systems at high levels. They openly exchanged information with the AET on the type and frequency of maintenance and test activities, problems they had experienced, and potential areas for improvement. Recent improvements have been made to PM programs and procedures for E&BP equipment at practically all of the sites.

The AET found varying degrees of understanding and application of good engineering practices for maintenance of E&BP equipment. The AET found areas of technical expertise and program excellence at some sites that could help other sites to improve in equivalent situations. Many examples of identical or similar equipment types were found where shared information such as design features, procedures, maintenance practices, and lessons learned from operating experience would be useful to personnel responsible for E&BP system design, operation, and maintenance. However, there has been little communication among sites concerning E&BP systems. During the site visits it became obvious that maintenance personnel were: (1) not aware of the designs, problems, and practices at other sites, and (2) very interested in whether other sites were experiencing similar problems, and if so, how they were dealing with them. The AET detected a willingness to communicate with other sites, and also to learn from experience in the commercial nuclear industry that might be applicable to their sites. The AET believes that benefits from communication with counterparts at other sites is a key ingredient for improving E&BP reliability.

Therefore, DP-9 and DP-62 sponsored a workshop on emergency and backup power supplies for DOE Headquarters, Operations Office, Area Office, and Contractor personnel responsible for the design, maintenance, and operation of E&BP equipment. The workshop was held June 8 - 10, 1993, in Albuquerque. The purpose of the workshop was to establish and promote communications and to share information and technical expertise among DOE sites regarding operating experience, effective programs and practices, solutions to problems, and methods for improving the performance of E&BP supplies. The workshop provided the preliminary findings and recommendations of the AET review of E&BP systems, and included presentations from E&BP equipment vendors on recommended maintenance practices. Many of the sites that

participated in the review made presentations concerning experience at their sites and methods used to resolve problems and improve E&BP system equipment availability. The workshop stressed the importance of understanding the design basis for providing E&BP capability, provided guidance on how to analyze and document the safety significance of E&BP supplies, and emphasized the need for E&BP equipment important to safety to be identified, classified, recognized, and treated as such by designers, users, and maintainers.

At the workshop, the AET proposed that a BPWG be formed comprised of DOE and contractor representatives from each DP site where E&BP supplies are used to provide backup power to systems and equipment important to the safety of workers, the public, or the environment. The BPWG would provide a forum for effective communications on a continuing basis between DOE Headquarters, Operations Office, Area Office, and Contractor personnel responsible for the design, maintenance, and operation of E&BP equipment. Objectives of the BPWG would include operating experience feedback, coordinating training efforts to meet overall needs within the DP complex, sharing successful maintenance management techniques and effective solutions to E&BP supply problems, and promoting the use of applicable industry standards and good engineering practices. Sharing information, ideas, and technical expertise regarding E&BP system design features, procedures, maintenance practices, and performance history should benefit those responsible for the proper operation and maintenance of E&BP equipment and lead to increased E&BP system reliability. This should be particularly beneficial at this time when many sites are evaluating and upgrading both electrical systems and site programs and procedures that will affect E&BP system performance. The recommendation for forming a BPWG was met with enthusiasm. A BPWG was subsequently formed and held its first meeting September 20 - 22, 1993 at LLNL. Continued support is required from both DOE and M&O contractor management for the BPWG to work effectively toward achieving the benefits that result from improved E&BP system reliability.

The AET believes that existing industry standards (e.g., published by the Institute of Electrical and Electronics Engineers [IEEE]), DOE Order 4330.4A, "Maintenance Management Program," and DOE Order 5480.23, "Nuclear Safety Analysis Reports," and current initiatives such as upcoming efforts to improve configuration management programs at DOE sites, should form the fundamental basis necessary to ensure the proper design, operation, and maintenance of E&BP equipment important to safety. This chapter presents the AET's findings relative to the situations, conditions, programs and practices for maintenance and testing of EDG, UPS and battery systems at the sites visited, and provides the basis for recommendations where the AET believes improvements should be made in maintenance and testing practices for E&BP system equipment. The AET believes that a reasonable approach for disposition of certain recommendations is to assign them to the BPWG for review and evaluation (i.e., have the recommendations addressed by those responsible for design, operation, and maintenance of the equipment). Defense Programs is coordinating and actively participating in BPWG activities.

6.1 Emergency Generators

Emergency generators as used in DOE facilities are independent electrical power supply units consisting of an internal combustion engine (that runs on either diesel fuel or gasoline) directly coupled to an electrical generator with associated instrumentation, controls, protective features, and auxiliary systems. These units are used extensively throughout the DOE complex. The sites participating in the AET review have a combined total exceeding 500 diesel engines/generators. With the exception of reactor facilities, significant physical differences exist between EDGs at DOE facilities and EDGs at commercial nuclear power reactors. The EDGs at DOE facilities are in general much smaller, with rated capacities in the range of 10 to 1250 KW (at many sites, over 80 percent of the EDGs were rated at 150 kW or less; at one site many EDG capacities were in the range of 400 to 800 KW) as compared to approximately 3000 to 5000 KW for commercial reactors. There have been a few cases of EDG overloading at DOE facilities, but for most EDGs, the normal bus load is between 50 and 75 percent of their continuous rating, and therefore, EDG overload does not appear to be a prevalent concern. The EDGs at DOE facilities are less complex and, therefore, should be less prone to failure after start. Many installations do not have complicated air start systems, or turbochargers, and have fewer automatic trip signals. Preventative maintenance and surveillance practices are less complex because of the smaller size and simpler EDG designs.

The EDGs at commercial power reactors are designed and installed as safety related equipment, but less than one-half of the EDGs at the DOE sites reviewed by the AET were considered by the M&O contractors to be important to safety. Commercial nuclear reactors employ redundant EDGs to supply emergency power to loads needed to achieve and maintain safe shutdown conditions for analyzed transient and accident scenarios. However, DOE sites have a much larger number of EDG units with more diverse application. Some EDGs at DOE facilities serve as either a second backup system, or are continuously running and do not require automatic start and load on loss of normal power. Many of the DOE non-reactor nuclear facilities use either a single EDG or multiple smaller EDGs for specific functions important to safety (such as backup power for building exhaust ventilation and filtration system fans, cooling system pumps, and emergency switchgear for lighting, etc.). At DOE reactor facilities, EDGs providing power to decay heat removal and accident mitigation systems are considered important to safety. For three of the sites reviewed, 86 out of 230 EDGs were considered "important to safety." The following sections cover findings pertaining to the maintenance, testing, and material condition of EDGs at DOE facilities.

6.1.1 EDG Testing & Maintenance

There is wide variation in the PM and testing practices at different sites and between facilities at the same site. This may be due, in part, to the differences in safety significance of the various EDG applications.

The AET found that EDGs at most sites are start tested either weekly, bi-weekly, or monthly. The monthly surveillance test interval is comparable to that for EDGs at commercial reactor facilities. Frequent fast start testing

of large EDGs is a concern and was found by the NRC to be detrimental to EDGs. Fundamentally, the EDGs used at commercial reactors are very large machines such that adequate lubrication may not be available on fast starts without prelubrication. Additionally, the lubrication problems together with the thermal stresses created by fast start and load have been found to result in premature engine wear. Smaller engines are less prone to these effects. Most DOE EDGs are much smaller than those used in commercial nuclear power plants and therefore, are less susceptible to this problem.

In conjunction with scheduled start tests, the EDGs are often inspected to verify adequacy of lubrication (i.e., engine oil level and pressure), and to confirm that circuit breakers, coolant system, and fuel system components are in their proper lineups. It is also general practice to ensure that fittings are tightened, belts and hoses are checked for excessive wear, links are connected, machines are maintained clean, and filters are replaced. Most weekly or monthly tests involve a start and a short duration run. The run time is usually not sufficiently long to verify proper EDG operation for a sustained period. For example, an engine that over-heats after a period of time would not be detected by a short duration test. Also, since the machines at most facilities are started manually and tested at no-load on the generator, the surveillance test of the generator only verifies that the voltage regulation (field) and frequency control are functional, and that the EDG rotates without bearing problems at no-load conditions. No-load or light-load operation does not fully test vital equipment and functions such as the excitation system, the response of the speed control (governor) under load, the load carrying capability of the generator, protective trip/alarm circuits, or switchgear.

The testing of EDG units at or near rated load (i.e., nameplate rating) is often not performed, or is performed on a less frequent schedule, usually annually. Some sites do perform more frequent load tests. At least one site tested some of their EDGs by disconnecting the offsite (normal) source and allowing automatic start and loading of the EDGs. This is the preferred method of testing because it tests all system components that are required to function during an actual loss-of-power event. However, existing designs often make this method of testing impractical because of the potential impact on facility operations. A periodic functional test of the complete EDG system as a whole (i.e., where the loss-of-power condition is simulated in a manner that exercises all key components, including the circuits that automatically sense the need for and start the EDG, load the EDG, and monitor EDG performance) is considered a good practice that should be performed at least annually for installations where EDG backup power is provided for safety reasons. In some instances, facilities do periodically perform a simulated loss of power test to verify automatic start and load of EDGs with actual loads on the EDG buses. However, it appears that the initiation circuits that provide EDG automatic start signals are often not subjected to routine periodic testing. The EDGs are manually started and connected to their buses by the utility operators, for both load and no-load tests.

Except for a few DOE facilities, EDG supplied power is provided using a "dead-bus" transfer (i.e., the normal power source must be disconnected from

the bus so that the bus is deenergized or "dead" prior to connecting the EDG backup power source to reenergize the bus). Most EDGs are not equipped with synchronizing capability (i.e., circuitry that allows two separate power sources to be connected simultaneously or "paralleled" to the same bus in phase or "synchronized" to prevent equipment damage), making it necessary to disrupt normal power to loads (which often causes temporary loss of desired functions) before the loads can be transferred to the EDG for testing purposes. Advantages to providing capability to synchronize emergency generators with the normal off-site source include the ability to perform full-load tests without interrupting power to house operating loads. However, in many cases it may not be cost effective to back-fit EDG synchronizing capability. The only way to accommodate load testing at many facilities would be to provide load banks for machines where load testing is desired.

The accumulation of time under no-load operating conditions presents a concern for reliable EDG operation. No-load or light load operation causes detrimental effects such as build-up of deposits on cylinder walls, valves, piston rings, etc. that can lead to mechanical failure, and buildup of deposits in the exhaust system, potentially resulting in fire. For many EDGs, the total connected load is very small, often less than 50 percent of rated capacity. Prior to load testing at some facilities, operations personnel routinely turn off or disconnect equipment they believe might be harmed or affect facility processes. Therefore, the "house load" connected during the load test is minimal; sometimes less than ten percent of the nominal connected bus loads. Some of the EDG load test procedures reviewed by the AET did not specify a minimum required loading criteria for the test results to be considered successful. Chapter 7 of this report addresses the importance of cooperation between facility operating organizations and maintenance organizations to ensure proper maintenance and testing of E&BP equipment.

One EDG vendor informed the AET that in general, EDGs are not efficient and do not run well when loaded to under 35 percent of the rated capacity, and cautioned personnel to be aware of misapplications where the EDG is oversized for its connected load. This may be a problem where large loads are deleted over the years; replacement with a smaller unit may be appropriate in these cases.

Based on discussions with a major manufacturer of EDGs used at one site, Plant Engineering recently decreased the EDG test frequency from bi-weekly to monthly. The EDG manufacturer expressed concern over the frequent number of tests at or near no-load conditions. Plant Engineering indicated the manufacturer informed them that running the engines at or near no-load results in "cylinder glazing" (i.e., a glazing forms on the cylinder walls that is very slick, allowing oil to pass between the piston rings and the cylinder walls). Site representatives stated that they had experienced excessive amounts of oil entering the exhaust system and exiting the exhaust stack, a condition called "wet stack," resulting in an oil usage problem. Running at or near no-load, even for periods of up to 30 minutes, was said not to allow the rings to expand to get a good seal, resulting in oil "blow by" (i.e., oil bypassing the rings). The M&O contractor stated they were

told by the manufacturer that the annual four hour EDG surveillance test run at full rated load was sufficient to cure the glazing problem. The site also indicated that the bi-weekly test frequency posed a significant burden in terms of cost and manpower.

Also, the manufacturer recommended that the duration of the test runs be shortened from 30 minutes to 5-10 minutes to reduce the effects of no-load testing. The performance data received during the shorter run time was said to be valid for all parameters except engine temperature. The manufacturer indicated that the problem caused by longer no-load test runs is formation of condensate in the engine oil. Operation at or near no-load conditions does not allow engine operating temperature to reach a high enough value to dry out the condensate formed, and the shorter runs result in less condensation. Some manufacturers of large EDGs recommended a duration of several hours for full-load tests of EDGs used in standby applications. In addition to load testing, one EDG vendor recommended weekly starts of short duration in order to keep the engine upper internals lubricated to prevent excessive engine wear.

Because most EDG installations do not include design features to readily accommodate load testing, and since the total connected load for many EDGs is only a fraction of the rated capacity, load banks are sometimes used in order to allow full-load tests to be performed. Some sites have recently procured resistive (not reactive) load banks which are adequate for testing most EDG units at "name plate" ratings to demonstrate full load KW carrying capability. However, because the load bank is resistive, total KVA ratings for the larger EDGs would not be demonstrated. A benefit of using a reactive load bank is the ability to simulate the large reactive load and related inrush current incurred when loading large motors to demonstrate capability of the EDG to accommodate the varying load power factor occurring in actual practice. The availability of adequately sized load banks at some sites is scarce. Several sites were planning to purchase additional load banks. Use of a load bank requires disconnection and reconnection of large electrical cables, which resulted in damage to terminations at one site.

Load tests for EDGs at commercial nuclear facilities and other industrial applications (e.g., hospitals) are normally required at monthly intervals. These tests are typically performed at 90 to 100 percent of the EDGs continuous rating for intervals of not less than one hour. The test programs at some DOE sites require very infrequent load testing of EDGs (e.g., annually).

Manufacturers should be consulted for guidance on the appropriate tests, and test conditions (durations, frequencies, etc.) for each EDG application. IEEE Standard 387 "Criteria for Diesel Generator Units Applied as Standby Power Supplies for Nuclear Power Generating Stations," and NRC Regulatory Guide 1.9 Rev. 3 "Selection, Design, Qualification, and Testing of Emergency Diesel Generator Units Used as Class 1E Onsite Electric Power Systems at Nuclear Power Plants" provide guidance for (1) testing EDGs to demonstrate their continued ability to perform intended functions acceptably, and (2) recordkeeping practices that will assist in analysis of overall EDG performance.

In some cases, portable EDGs had been overlooked in regard to testing and PM because they had not been assigned component identification numbers. Corrective action has since been taken to provide unique identifiers to all EDGs so that they will be included in the normal test and maintenance program. Proper labeling of equipment helps to ensure the intended equipment is being operated, tested, or maintained, and that the correct procedures are being used. At one site, laboratory instruments were damaged when they were plugged into an unlabeled receptacle that supplied voltage at a different level than used elsewhere in the laboratory.

Sites are beginning to implement DOE Order 4330.4A, "Maintenance Management Program." For example, some sites are sampling and testing EDG lubrication oil and coolant for evidence of engine wear, and fuel for moisture and algae growth. This is consistent with industry practice for commercial nuclear plants and industry standards on fuel quality. Diesel fuel stored in a large tank at one facility had to be chemically treated because of algae contamination.

It is clear that site managers are becoming more sensitized to the need for reliable EDG performance. Some sites have developed comprehensive and well defined surveillance procedures for monitoring and verifying equipment operability, and detecting abnormal conditions. Continued emphasis should be placed on improved designs which assure a comprehensive functional test of components (including initiation circuitry and system switchgear), facilitate load testing, and avoid the problems of no-load operation. This of course, should take into consideration the significance of failure of specific EDGs; a graded approach should be applied when weighing the importance of design and testing changes.

The AET reviewed a representative sample of the maintenance procedures at each site, and performed cursory reviews of maintenance organizations to obtain a general understanding of the maintenance process. The AET also reviewed problem areas and causes for failures with contractor personnel responsible for EDG maintenance activities. It appeared that maintenance procedures were consistently used, and that procedure reviews were performed as a quality assurance measure. Although only one vendor technical manual could be found for the eight EDGs reviewed at one site, vendor manuals were generally available at most sites. The AET review confirmed that the procedures usually contained pertinent information from the EDG vendor manuals. However, the procedures were usually general, without specific guidance, prerequisites, cautions, or acceptance criteria. It was not clear that maintenance and surveillance testing procedures contain the substance and quality necessary to maintain desired EDG reliability. It appeared that supervisors ensured adherence to procedures and policies; however, it was not apparent that adequate policies and programs exist to ensure that adequate data are collected or that maintenance organizations benefit from "lessons learned" as operating experience is gained. The AET believes that additional systems engineering involvement to assess maintenance rework, and to evaluate inspections and testing, would be beneficial and would advance maintenance goals.

One concern identified by the AET is that common procedures were often used for multiple EDGs of different sizes, designs, and from different manufacturers. Machine specific procedures provide better assurance of comprehensive maintenance and testing of machine unique features and characteristics, and reduce the potential for mistakes (e.g., ensuring proper lineup on return to service, etc.). In addition, most sites have limited manpower for PM testing, and most technicians are not thoroughly knowledgeable on all EDG designs. At one site, the EDG PM task orders are basically indistinguishable in their application to any particular EDG. All EDGs are run monthly for 1.75 hours regardless of whether the EDGs have load banks or not. There are no instructions on how to run the EDGs (loaded or unloaded). At some sites, maintenance procedures are being upgraded to address engine specific features. The new procedures reviewed were more detailed than previous procedures.

At one site, maintenance is performed on a semi-annual and annual basis for all but the normal-run engines. Maintenance on the normal-run engines (i.e., those EDGs that are run continuously as opposed to those EDGs on standby status) is performed monthly. The semi-annual maintenance includes oil change, lubrication, coolant check, check for unusual noises, and adjustments. The annual maintenance includes air filter check/replacement, lubricate or change starter if required, and fuel check and filter replacement. Starters and batteries are replaced every two years. The types of EDG maintenance activities performed at various sites are similar with the exception that starters are not routinely replaced at specified intervals. A few sites routinely replace EDG batteries as a measure to improve the reliability of EDG starting power, but the frequency of replacement varied (one site replaced the batteries yearly, and another site replaced the batteries every four years).

The AET reviewed engine preventative maintenance procedures and engine vendor manuals and found that vendor recommendations were generally incorporated into maintenance procedures. However, vendor recommendations are not always clearly specified or may not be appropriate for EDGs which are normally in the standby mode. Basing the frequency of preventive maintenance activities on the number of engine hours elapsed since the activity was last performed may not be adequate because of the long time periods required to accumulate hours. The design basis for each EDG application should be thoroughly evaluated to determine the appropriate criteria and practices to be included in preventive maintenance programs. Engine hours are typically checked each month where the maintenance frequency is based on engine hours elapsed. Typical maintenance frequencies found for DOE sites are semi-annual, annual, or based on engine hours elapsed, and vary depending on the specific EDG involved.

6.1.2 EDG Starting System Batteries

Problems associated with batteries in EDG starting systems were found to be the dominant contributor to EDG failures, and were identified as an outlier adversely affecting EDG reliability. Maintenance personnel at several sites indicated that over 50 percent of EDG problems were related to the starting batteries. A common problem was said to be battery charger output fuses.

Once the fuse blows, the charger can no longer recharge the batteries. Since the batteries continually supply control power to the EDG instrument panel upon failure of the charger output, the batteries can become depleted within several days. Since this failure mode is not automatically detected or alarmed, the EDG will often remain incapable of starting until the problem is detected and corrected following the next EDG demand. The next demand would likely be the next scheduled surveillance, but could be in response to an unplanned outage. Battery maintenance and surveillance programs were found to be weak, and often did not conform with current standard industry practice. Battery chargers appear to rarely be periodically calibrated or maintained.

The questionable reliability of the starting batteries was the primary factor in establishing a more frequent EDG surveillance test interval at one site. At two other sites, the AET found instances where EDG starting batteries were being charged or equalized prior to EDG testing. At one of these sites, the AET was told that the reliability of the starting batteries was so poor that they knew the EDG would not start, and would therefore fail the test, if the batteries were not charged prior to the test. This practice is strongly discouraged because the testing no longer gives a true indication of whether there are problems, or if the EDG system can respond as designed to an actual loss of power demand.

Given the problems with EDG starting batteries, the AET recommends that battery maintenance practices be evaluated to ensure that monitoring frequency and maintenance tasks are adequate. Out-of-tolerance conditions and conduction path problems should be detected. At one site, the EDG starting batteries are not maintained to the same standards as the UPS batteries. From discussions with maintenance support personnel and from a review of the UPS action plan (written to resolve UPS problems/failures), emphasis is being placed on UPS batteries, but EDG batteries have been neglected. There is an effort to revise the PM task orders and procedures to bring the EDG batteries to the same level as UPS batteries. This is to include the requirements of IEEE Standard 450 "IEEE Recommended Practice for Maintenance, Testing, and Replacement of Large Lead Storage Batteries for Generating Stations and Substations" related to intercell and battery post terminal resistance. A review of revised procedures indicates that both IEEE 450 and IEEE 1106 (for NiCad batteries) are now being referenced.

It is obvious from the review of PM task orders and procedures that EDGs and UPSs are treated as systems, and that the batteries are included as part of the system. Although changes are being made at some sites to make PM and testing of EDG batteries more consistent with the improvements being made for UPS and station batteries, the AET concluded there is a general deficiency in the PM practices related to EDG batteries. Part of the problem appears to be that EDG vendor manuals, which contain detailed information on the design, operation, and maintenance of the engine mechanical and generator portion of the EDG system, often do not contain equivalent information for adequate maintenance and testing of the starting batteries. A possible solution to the problems of neglect and inadequate PM for EDG starting batteries might be to include all batteries in a separate overall site program so that starting batteries are no longer "lost" under a

general EDG or UPS system maintenance program. The program would establish contact with EDG and battery vendors concerning proper PM for starting batteries to improve their performance, and examine existing industry standards such as IEEE 450 to determine which battery maintenance requirements and good engineering practices should be incorporated into PM task orders and procedures. In addition, the program should specify the various parameters to be monitored and records to be kept for trending of battery performance, define acceptance criteria, and provide corrective actions for when the acceptance criteria are not met. The apparent benefits of a well-planned proactive PM program for EDG starting batteries would include saving battery replacement costs by significantly extending battery life, and reducing the problems/concerns associated with disposal of battery toxic waste.

6.1.3 EDG Reliability

The AET examined documents such as surveillance test records, PM records, facility operating logs, and personal logs of system engineers at several sites for the purpose of obtaining data for calculating actual EDG reliability and availability. However, the AET experienced difficulty finding useable data for performing the calculations. The reliability of an EDG is defined here as the probability that the EDG system will successfully carry out its mission (i.e., to start, run, load, and provide quality power to its output bus for the required duration). This definition is used by the NRC in NUREG/CR-5078 "A Reliability Program for Emergency Diesel Generators at Nuclear Power Plants." The AET was able to find some data for calculating EDG reliability, but the quality of the data was poor and would not yield meaningful results. Documentation concerning EDG performance history was either unavailable or incomplete at most sites. The AET was generally unable to find complete records concerning the number of attempted and successful starts for EDGs. As an example, the best available information for the two EDGs at one nuclear facility came from the shop responsible for EDG maintenance, and from the personal log of the responsible facility engineer. However, there were a number of discrepancies between the two data sources. Neither source was a formally controlled document (i.e., they are not mandatory, structured, or periodically reviewed for adequacy of content in accordance with established procedures). A partial reason for discrepancies between the two sources of data is believed to be that one of the sources did not include challenges from unplanned outages, or failures that may have occurred in response to unplanned outages.

Strict criteria for determining successes versus failures under test or actual demand challenges to EDGs are not uniformly applied at DOE sites. It is the AET's understanding that initial failures of EDGs to start and/or run are sometimes not documented as failures when the cause for the failure is easily and quickly corrected, and the ensuing start and run attempt is successful. Some facilities record a start as a success if the EDG starts even though its output breaker may be found disabled, or if the engine overheats during an extended run. Conversely, an EDG might be considered to fail a test if a parameter was slightly out of specification although the EDG was still fully capable of performing its design function. An EDG that

fails a test because of a slightly out of tolerance condition (e.g., voltage or frequency off by a small percentage) would not be considered significant if the EDG was still capable of providing adequate power to its loads, whereas the failure of an EDG to start or run in response to an actual demand may be highly significant, depending on facility design and/or the status of facility operating conditions at the time. A failure to start on demand may not be significant if sufficient time is available to correct the failure and start the EDG or connect a portable replacement diesel generator. Because interpretations of EDG system operability often differ from facility to facility and between sites, the AET concludes that standard definitions are needed for variables affecting EDG reliability calculations (e.g., what constitutes a valid start, a failure, and an operable EDG). There is also a need for better guidance on how to monitor and assess EDG reliability and availability, and how to maintain EDG reliability and availability at acceptably high levels. NRC Regulatory Guide 1.9 Rev. 3 provides definitions for valid starts and failures.

The AET Interim Report "Emergency Diesel Generator Reliability at DOE Facilities," dated April 1992, concluded that EDG reliability was generally near or above 90 percent, and subsequent calculations for EDGs at other sites have yielded similar results. However, it is not clear that all EDG system failures have been properly recognized, documented, and reported. Improvements in the quality, quantity and documentation of data are necessary before accurate determinations of EDG reliability can be made. The AET was unable to numerically assess EDG availability (i.e., the portion of time that an EDG is available to provide back-up power during the time that back-up power would be needed upon loss of normal facility power) for any of the sites because the necessary documented information (e.g., EDG down time for repair, testing, or maintenance) did not exist.

6.1.4 EDG Performance Records

Because of the problems experienced in finding data to perform reliability and availability calculations, the AET elected to perform additional assessments to determine the overall quality of equipment performance records. Preventative maintenance and corrective maintenance activities were usually recorded, however, documentation of observations and comments with regard to problems, component failures, and reasons for maintenance activities were typically poor. In some instances, a significant amount of testing was done but no records were kept. Even the best available data were incomplete and of non-uniform quality.

The AET found that performance data for the E&BP system equipment are not collected, maintained, trended, or evaluated by a single site organization as is done at commercial nuclear facilities. Some data are maintained by site-wide organizations responsible for specific aspects of equipment operation (e.g., generator electrical, electronic section, engine mechanical, surveillance testing, etc.), however, much of the available data were not collected with the intent of analyzing whether the equipment is acceptably reliable. What little information is available is often kept by an individual who is only responsible for certain aspects of the specific facility where the equipment is located. There are typically no formal

procedures used site-wide for documentation of performance data, and as a result, the quantity and quality of information available often varies greatly from facility to facility at a given site. Most of the information concerning EDG runs at one site was collected for the purpose of developing exhaust emissions release data for environmental reporting purposes. The mechanical maintenance department at another site only maintained records for the purpose of time keeping and manpower justification. At one site where record keeping and EDG performance data used to be non-existent, a new EDG maintenance file was recently established for the purpose of planning, scheduling, and recording EDG test results.

Inspection of the test data indicates that there is a need to provide significantly more complete test information than is presently being documented. In addition, the data base is not set up in a manner that permits accurate trending of equipment performance. Better documentation of maintenance activities is needed to support failure analyses, and to trend EDG performance and predict degradation of components, and to identify problem areas that might require heightened management attention. The AET found that, in general, trending of EDG performance history was not being performed and historical information was not readily available. Regulatory Guide 1.9, Rev. 3 and IEEE Standard 387 also address EDG performance data recordkeeping and analysis. In general, the AET found that better information was available concerning the recent history of E&BP equipment used in more safety significant applications, partially because of recent improvements in maintenance and test procedures in response to DOE Order 4330.4A, "Maintenance Management Program."

The implementation of a maintenance history and trending program as described in DOE Order 4330.4A, "Maintenance Management Program," should help to correct this deficiency. Section 16 of DOE Order 4330.4A states that a

"maintenance history and trending program should be maintained to document data, provide historical information for maintenance planning, and support maintenance and performance trending of facility systems and components." The stated objective is "to be able to readily retrieve equipment maintenance, performance, and reference information in order to improve reliability."

DOE Order 4330.4A is to be implemented using a graded approach, corresponding to the importance of specific equipment to safety. There is clear indication that the Order is being addressed particularly with respect to the scheduling, tracking, and development of work packages and procedures for maintenance, repair and test activities. The team believes that improvements currently being developed or implemented concerning EDG operation, testing, maintenance, record keeping, performance trending, and procedures for EDG program activities should result in the future availability of better data for the statistical evaluation of performance and reliability.

6.1.5 PM Procedures and Data Sheets

An area that requires significant improvement is the quality of data sheets used to record the results of E&BP system test and maintenance activities. Data sheets and procedures often did not contain provisions to record meaningful data, require sign off spaces for critical steps, indicate specific parameters and their normal ranges to allow verification of proper operation, include acceptance criteria, provide instructions for what constitutes a failure and what to do in case of a failure, and often did not record as found/as left conditions or root cause information. Data sheets were frequently found to provide little useful information for observing trends and anticipating failures.

Although significant differences exist in types of activities for annual and monthly PM, the data sheets used are often the same for both. At one site, the test procedure for generators is a generic check list written for all types of generators (both diesel and gas) and, with the exception of generator frequency, does not contain acceptance criteria. The procedure does not record "as found" data and therefore, the data sheets provide very little information usable for observing trends and anticipating failures. Procedural steps were often too general to ensure successful completion of intended tasks. For example, the step would say to "check all fluid levels" without listing the specific fluid levels to be checked; or "check battery charger output" without specifying acceptable output voltage values.

Many data sheets do not include sign-off spaces to be initialed and dated by the maintenance technician as the individual steps are performed. This is especially important for those steps which could potentially involve hazards to personnel or equipment, or are essential to successful completion of the maintenance activity. Sometimes, the data sheets and the associated procedures are one in the same. When developing procedures and data sheets, consideration should be given to requiring independent verification (i.e., sign off by a second qualified individual not involved in performing the step) for those steps that could result in severe equipment damage or personnel injury if not properly performed. Data sheets often did not include adequate space for written comments for documenting problems, observations, and explanations, or identify specific contacts (individuals and organization) responsible for correcting problems, removing obsolete information, and adding new information through revisions. Data sheets were often not formatted to record specific data for the PM/test activity being performed (i.e., where the numeric step on the data sheet corresponds to the numeric step in the procedure). One surveillance procedure reviewed by the AET required that data be recorded at specified time intervals, but the data sheet did not provide corresponding spaces to enter the data. The data sheets at several sites were blank pages available for the maintenance technicians to record the data they believe the procedure requires.

Some procedures failed to emphasize safety related information, cautions, and warnings. Some procedures contained no references to vendor manuals or other relevant procedures or safety information, or contained incorrect references. At one site, a procedure used for EDG testing referred to an attachment for acceptance criteria to be used to determine if the EDG successfully passed the test, but the attachment did not contain acceptance criteria.

At one site, the maintenance department performed procedural walkdowns with facility operations and engineering personnel. This proved to be a worthwhile effort that identified several problems such as not allowing sufficient time to perform the procedure, identification of procedural steps that were wrong or needed correcting, etc. Some steps were found to be generic and not adequate for the situation. For example, there was a single generic step for returning equipment to service following maintenance which relied on site-wide lockout/tagout training, versus giving the specific steps unique to the equipment involved.

As can be seen from the instances discussed above, the availability and quality of records covering equipment performance history is poor. However, sites are beginning to develop systems for maintaining appropriate records in accordance with DOE Order 4330.4A. While there are still disparities, and vendors technical manuals are often not referenced, improvements are being made to base maintenance procedures on manufacturer's recommendations. Continued effort in this direction is necessary to incorporate appropriate standards requirements in maintenance documents, to use vendor specific information, to include acceptance criteria, and to implement other programmatic improvements indicated herein to arrive at a more controlled, comprehensive, and consistent approach to maintenance. DOE Order 4330.4A, in Chapter II, Section 16, "Maintenance History," and Section 17, "Analysis of Maintenance Problems," provides guidance for the development and use of a maintenance historical program, and for the use of the information captured in resolving root causes of problems and reducing their recurrence.

"The maintenance history program should provide a system to document component identification and description, vendor reference information and correspondence, diagnostic monitoring data, corrective and preventative maintenance identification information."

Some of the uses of maintenance history are: failure analysis (the program provides some of the data needed for analysis and trending), preventative maintenance (the program provides useful information for identifying needed maintenance program changes), and conduct of maintenance assessments. The Order provides detailed information relative to equipment identification, data identification and collection, program use, and the analysis of problems. The implementation of this Order should improve the quality and availability of performance records so that trending and related maintenance actions may be taken to improve and sustain equipment reliability. Continued emphasis should be placed on the implementation of DOE 4330.4A with regard to maintenance records. This should be done using a graded approach which places emphasis on equipment having the greatest safety significance first and which dictates the level of attention received throughout its useful life.

6.1.6 EDG Material Condition

The AET inspected several EDG installations at each of the sites visited. The material conditions found were not totally consistent from site to site and from facility to facility. The majority of EDG installations appeared in good condition and clean with equipment generally in a well kept state.

Enclosures were clean and orderly, and industrial safety appeared good. Most EDGs were clearly and uniquely identified. Engine block heaters were operational, and belts and hoses usually appeared in good condition.

While there were many instances where appropriate care was provided, there were instances where the material condition needs improving commensurate with the EDGs safety/mission basis. Oil leaks were the most common problem. At one facility, two EDGs were in a serious state of disrepair. One site had EDGs with extensive oil leaks and one EDG was out of service for unscheduled repairs. At another facility, two of the three EDGs appeared badly maintained and were leaking fluids onto the starting batteries. The starting batteries often appeared neglected compared to the remainder of the EDG installations. The batteries frequently were dirty or greasy, and appeared to not have been maintained for long periods of time. In addition, the batteries were sometimes poorly physically supported (e.g., mounted on a plywood box or sitting loosely at the bottom of the enclosure). Very few starting battery installations appeared to have seismic supports or restraints. Many EDGs are located outside, often with minimal protection from the weather. These EDGs had more damaged parts than EDGs located inside, but most were in fair condition. The air intake for one EDG was found clogged with grass and leaves.

Poor material condition of equipment is often indicative of a general attitude towards maintenance that lacks emphasis on its importance in relation to the reliable operation of equipment.

6.2 Uninterruptible Power Supplies

The UPSs provide an uninterrupted source of power to important instrumentation and control systems to mitigate the effects of a loss of normal power. They also provide a continuous supply of quality power for systems sensitive to electrical system disturbances caused by switching loads on and off, line faults, power transfer, etc. Typical UPS designs include various combinations of rectifier/charger, battery transfer and bypass switches, and inverters (See figure 3.2).

There are many applications of UPS systems at DOE facilities; a significant number of which are used in safety related systems, computer systems, radiation monitoring and alarm systems, and security systems. The function of an UPS is frequently more important to safety than that of an EDG. It is important to maintain these UPS systems to assure their availability and reliability to perform their design function.

However, the quality of maintenance and surveillance programs for UPS systems did not always appear commensurate with their importance. For example, the failure of UPS systems to carry loads for the duration of a building power outage was a repeat occurrence at one site. In most of these cases it appears that the batteries were discharged prior to power restoration, indicating perhaps either poor UPS system maintenance or improper sizing of UPS batteries.

6.2.1 UPS Testing & Maintenance

The AET review included maintenance and testing programs and procedures for UPSs. As with EDGs and batteries, the AET found variation in the quality and degree of maintenance and testing practices and procedures. Recent improvements to PM procedures have been made at several sites, some based on NFPA-110A. Some examples of the situations found at the various sites are discussed in the following paragraphs.

High priority was given to upgrading UPS battery PM procedures at one site because of recent problems with UPS failures. Procedures were being upgraded at the time of the review. A generic battery PM procedure was in place covering all types of batteries, i.e. lead-acid, sealed lead-acid, nickel cadmium. It is expected that the existing generic battery PM procedures will evolve into a separate procedure for each battery type.

At one site, there was a set of formal procedures for monthly, quarterly, and general housekeeping PM activities at one facility, but at a different facility, PM procedures did not exist and no PM has been conducted for about six years. The batteries associated with the UPSs generally receive the most PM attention. At one facility, monthly PM procedures require that the battery voltage be measured, the cell temperature and specific gravity be measured and recorded, and electrolyte level observed and corrected if necessary. On a quarterly basis, batteries are visually inspected for corrosion and cleaned, terminal post connections are checked and tightened as necessary, and terminal grease applied. However, from a review of PM procedures for the UPS batteries, it was not clear whether only the external surfaces of battery terminal assemblies were cleaned, or whether the terminals were disassembled to clean all internal contact points and the terminal connections retorqued upon reassembly. The concern is that corrosion which could lead to high resistance connections may not be visible in all cases. In addition to visual inspections and routine cleaning, periodic terminal resistance measurements of battery connections are necessary to ensure battery operability. Annually, the UPS is vacuumed, air filter replaced, and equipment inspected to identify overheated components, discoloration of printed circuit boards, or loose/broken connections. While these PM procedures reflect the vendor recommendations, certain guidance from industry standards such as IEEE Standard 450 were not always considered in their development. The procedures do not appear to reflect any special consideration for local conditions, for example, special filter replacements following activities in an area where significant amounts of dust are generated. In addition, the procedures did not provide for vendor-specific technical adjustments that are necessary subsequent to the replacement of components within the UPS.

Another facility at the same site did not have formal, documented PM or surveillance test procedures. Rather, when PM tasks are to be performed "Work Packages," describing the specific task are developed by a Work Control Group. The PM work packages are reviewed by the system engineer for completeness and conformance to manufacturer specific recommendations, including frequency of performance. Routine operational surveillance tests/checks, such as verification of alarm panel status lights, panel meter

indications or operability of cooling fans (if so equipped) are not currently performed. The degree of surveillance and testing of the UPSs appeared to vary substantially. For example, at a second facility the operations staff performs surveillance on the equipment daily to assure that all equipment indications (indicator lights and voltmeter/ammeter readings) are normal. A formal program of surveillance is in effect, complete with data sheets. Currently at this facility, UPSs are not tested in a comprehensive manner. There are no tests prescribed to verify capability to provide rated output power, to successfully switch over to the DC source when normal AC power is interrupted, to measure the distortion of the output power waveshape, or to detect other degradations which might indicate an impending failure. This practice is commonly referred to as "run-to-failure," which is typically followed by "emergency repair." In some cases, emergency repair involves replacing the failed equipment with new equipment. This approach is usually costly, and does not produce the reliability intended for UPS functions. Implementing a proactive program, which includes periodic testing and manufacturer recommended PM and parts replacement, should improve reliability and avoid repair and replacement costs and the impact on facility programs caused by down time.

At another site, one of the procedures addresses the maintenance of UPS on a quarterly and annual basis as follows:

Quarterly PM:

- check ventilation;
- inspect batteries for acid leakage & corrosion;
- inspect terminals for corrosion and tightness;
- perform circuit checks such as high voltage trip; and
- check and calibrate float and equalize voltages.

Annual PM:

Perform Quarterly PM plus:

- check low voltage alarm and trip points;
- check internal battery and terminal resistance;
- calculate the battery capacity; and
- replace batteries per criteria; also after 8 years.

The procedure was also comprehensive and provided a significant amount of detailed information on how to troubleshoot UPS problems. However, neither the data sheet nor the procedure itself contained acceptance criteria. Supervisory review of the testing was not documented. However, a draft procedure reviewed for this same site was found to be more comprehensive and included monthly, quarterly, and annual PM. The procedures for other sites evaluated contained similar PM requirements although on a somewhat different schedule. One performed weekly and semi-annual PM; another, monthly, quarterly, and annual.

The procedures and data sheets used for PM and testing of UPS systems at most sites were generally found to have the same problems described in Section 6.1.5 of this report.

Load tests are an excellent means of verifying proper operation of the UPS batteries under simulated emergency conditions. However, the time that the UPS remains operable can vary significantly from test to test due to differences in the loads in service at the time. The review of UPS test data showed varying times to reach the low voltage alarm. Therefore, it is recommended that the loading be standardized or recorded as a function of the time to give a basis for comparison, and to make the data more useful in identifying problems with the UPS battery.

In another instance, the AET requested the maintenance history records on UPSs for the past two years. In reviewing these records, the team generally found that the control of PM is somewhat informal. That is, if PM cannot be completed due to operational requirements or equipment unavailability, it is deferred but not rescheduled. The PM program includes provisions to monitor and report the backlog of incomplete activities, but this feature historically has not been used for assuring that PM activities are completed. Historical records could be improved by including a section for maintenance personnel comments on problems, actions taken to correct problems, and test results.

In summary, the treatment of maintenance and surveillance/testing is inconsistent from site to site and facility to facility. While some improvements are being made, the AET believes that additional improvements in maintenance and surveillance practices and procedures will increase the reliability of UPSs at DOE sites. Consideration should be given to the recommendations and requirements for maintenance and testing identified in industry standards (particularly IEEE 944, "Recommended Practice for the Application and Testing of Uninterruptible Power Supplies for Power Generating Stations"). DOE Order 4330.4A should be followed to assure a comprehensive and consistent approach to maintenance and testing, and to make use of information gained from maintenance and testing to assure adequate UPS system reliability. A testing program should be useful in providing trending information to allow replacement of parts prior to failure. In one instance, it appeared that a more thorough root cause analysis of UPS battery problems early in the equipment's life would have identified the cause for subsequent failures. Some factors that should be considered in development of a maintenance and testing program are the environment, acceptance criteria for test results/measurements, documentation for trending, and training of maintenance personnel on specific systems. Manufacturers' recommendations regarding the type of tests and the periodic replacement of parts should be included.

The significance of equipment failure should be assessed when determining the degree of maintenance and testing needed and a graded approach should be used. In some cases, it may be permissible to run components to failure if the consequences are never significant. A comprehensive maintenance and testing program should be provided to minimize failures during service

whenever the consequences of failure have the potential to adversely affect safety.

6.2.2 UPS Material Condition

The AET inspected numerous installations and found several situations where the material condition needed improvement, and a number of cases where the UPS environment should be upgraded. Some examples are discussed below.

At one site, the AET found two UPS units located in a large switchgear room. The UPS units had a rated operating temperature of 104 degrees Fahrenheit. Room cooling consisted of forced outside air. At the time of the walkdown, the ambient room temperature was 93 degrees Fahrenheit with the door to outside (a fire door) blocked open. The system engineer stated that, previously, a 15 KVA unit had shutdown and was bypassed due to high ambient temperatures.

At another facility, the UPSs and their associated battery banks have been in operation for only two years. Therefore, it was expected that their material condition would be good. However, due to nearby construction work, a significant quantity of fine dust had collected on both the air inlet filters and internal surfaces of the UPSs. The facility had a housekeeping procedure (soon to be implemented) to provide for inspection, cleaning, and replacement of the air inlet filter on an annual basis. Both UPS units and their associated battery banks are housed in a single room which, at the time of the walkdown, was found to be clean, well illuminated, cool and dry. Discussions with the system engineer revealed that room heating, ventilation, and air conditioning (HVAC) system outages have occurred, resulting in significant increases in the level of humidity in the room. Although the actual levels were unavailable, maintenance personnel stated that during loss of HVAC events, water droplets were observed on equipment and walls. The failure of HVAC was stated to have occurred twice a year. Coincidentally, the system engineer also described a failure of UPS involving several components. Although a root cause has not been determined, the exposure of UPS components to excessive humidity levels may have been a contributor. The need for UPSs to operate in a low relative humidity environment is recognized by the engineering staff; however, it was not clear that the operations staff is taking precautions to protect electrical equipment during HVAC outages.

At another site, the AET visited a building housing an UPS described by facility personnel as having a critical function. During the facility walkdown, this unit was found to be operating at an unsuitable ambient temperature. The building technical staff manager acknowledged this concern and stated the actual ambient temperature, as monitored by a local temperature recording device, was 100 degrees Fahrenheit while the ambient temperature rating of the equipment was only 80 degrees Fahrenheit. Also, since this UPS is designated as Class B equipment, it does not receive periodic maintenance. The unit is equipped with a built-in self test capability. If this self-testing feature indicates that service is required, the manufacturer is called in to perform the repairs. Due to the operation of the equipment in elevated temperatures, the manufacturer will

not guarantee any service work performed. The technical staff has taken action to evaluate changes to improve the operating environment.

At the request of the AET, the battery bank associated with one UPS unit was opened for inspection. A significant amount of visible corrosion was observed on battery terminal connections. The physical design and construction of the battery cabinet made it difficult to perform PM tasks such as routine cleaning of terminal connections, visual inspections, and replacement of electrolyte. Tight enclosures that provide limited access for PM activities were a common problem. In addition, many enclosures provided little or no ventilation. The problem of high room ambient temperatures is compounded by tight enclosures that retain internally generated heat around UPS electronics and batteries. One of the principal causes for adverse UPS operating environments was the heat and humidity generated by building services equipment such as pumps, compressors, and boilers located in the same room or adjoining areas. Elevated temperatures are known to cause accelerated aging of cables, capacitors, solid state devices, and other components, resulting in decreased reliability.

At another site, a problem existed which appears to be seasonal in nature. The problem was the number of insects found inside the UPS equipment. Due to the vast number of insects, there is an increased potential for clogged ventilation paths and short circuits.

At the sites and facilities evaluated, about 50 percent of the UPS installations were found in good condition with acceptable temperature and humidity environments; and equipment was clean without any sign of abuse, neglect or poor maintenance practices.

In summary, the material condition of a number of UPS installations needed improvement. However, in a number of these instances site or facility personnel were aware of the need and are planning to rectify adverse conditions. Continued emphasis and improvements in the maintenance programs are necessary to upgrade the environmental condition of UPS systems to avoid premature failures. Action is necessary to evaluate the use of UPSs to provide an appropriate classification relative to their significance and to provide PM consistent with that classification.

6.3 Battery Systems

Batteries at DOE sites are used in many important and often safety related applications, including: EDG starting, backup power for uninterruptible power supplies, switchgear control power, and telecommunications systems. The large percentage of batteries used at DOE sites are rechargeable lead acid or nickel cadmium batteries. Rechargeable batteries are divided into two basic types: the conventional flooded and the valve regulated (the so-called maintenance free battery). The long life flooded type requires a comprehensive maintenance, surveillance, and test program to ensure their reliability and performance capability. Although valve regulated batteries are generally replaced on a relatively short interval (approximately two years), they still require a significant amount of attention, care, and testing to ensure they are fully charged and capable of performing their

design function. In addition, valve regulated batteries require use of a special temperature compensated constant-current charger, and accurate monitoring of discharges is often required for the battery warranty to remain valid. Switching from flooded to valve regulated batteries is not recommended unless all design, operating, and maintenance characteristics have been carefully analyzed.

The AET reviewed maintenance and surveillance procedures on batteries, interviewed plant personnel cognizant of battery related activities, and inspected a number of battery installations. This was done to determine the level of maintenance and surveillance employed on battery systems, the consistency of approach, control of work activities and general conditions as found at battery installations.

As determined in meetings through statements made by site personnel, attention is being focused on battery maintenance/surveillance on a site wide basis. However, a wide variance exists in the quality of battery related procedures, training, and the material condition of batteries at the different facilities and sites.

At one site, a group has been formed to discuss battery issues and to disseminate information related to batteries in an effort to improve and make more consistent the approach to battery maintenance and surveillance. This is a well intentioned effort, however, it is not apparent how effective it will be since the involvement of the various facilities is said to be on a voluntary basis and there appears to be no formal process or authority to implement the good practices identified by the group. A central focus with management involvement is necessary if improvement in battery maintenance and surveillance practices is to be attained.

6.3.1 Battery Testing and Maintenance

A review of battery maintenance and test procedures for three facilities at one site found significant differences in the approach and level of detail included in the procedures. One facility has a separate comprehensive set of procedures for each battery that covers weekly, monthly, quarterly and yearly maintenance and testing activities. In addition, detailed procedures are available for performing the more infrequent battery service and performance discharge tests. The purpose of the service test is to demonstrate the battery's capability to carry its design load for the required time period. The purpose of the performance discharge test is to measure the remaining capacity as compared to design rated capacity. This is in effect an indirect measurement of battery age to assess remaining useful life and need for replacement. These two tests are the most realistic measure of a battery's ability to perform its function. Other tests, and maintenance and surveillance are also necessary to ensure the battery is fully charged and ready for operation. These activities provide some assurance of functional capability, but cannot replace a load test. In order to perform a meaningful "service (load) test", the load profile for the battery must be known. For the facility which has the comprehensive maintenance and test procedures, a load profile has been developed for each battery. In developing these load profiles and performing battery sizing

calculations, some batteries were found to be inadequately sized and were subsequently replaced with larger batteries. The AET was informed that the load profiles were used in conjunction with the battery sizing methodology of IEEE 485, "IEEE Recommended Practice for Sizing Lead Acid Batteries for Stationary Applications" to evaluate battery sizing. Some of the other facilities do not have battery load profiles available. Thus, whether the batteries are adequately sized or tested for their design load capability may not be known.

At this site a central service group has equipment specifically designed for performing service and performance discharge tests. The equipment provides for monitoring and recording individual cell voltages and battery current, and has the necessary load banks for performing service and performance discharge tests. Personnel qualified to perform these tests are available upon request by the various facility managers. However, requests have not been received from some facilities.

For the facility having comprehensive procedures, only two items require comment. The AET found that the periodic maintenance and test procedures allow for a wide range of acceptable battery room temperatures up to 110 degrees Fahrenheit. Lead acid batteries are designed for and specifications based on an ambient temperature of 77 degrees Fahrenheit. Temperatures below this value will significantly reduce the capacity of the battery and temperatures above will reduce battery life. For example, a temperature of +15 degrees above the 77 degree design temperature is said to reduce battery life by 50 percent, higher temperatures even more. Consideration should be given to placing greater constraint on battery room temperature. The second comment is related to the performance discharge test which does not call for measuring the resistance of intercell connections before performing the test. Since the sole purpose of the performance discharge test is to measure the battery's capacity, the battery should be fully charged and connections should be in good condition. Otherwise, if a test is being performed and connection problems occur during the conduct of the test, the test must be terminated and terminals cleaned and retorqued causing the test to be repeated with consequent loss of time. Checking (cleaning and torquing) the connections first may also save on the number of additional battery deep discharges which are a significant detrimental factor in battery life. The service test is the appropriate vehicle to test "as found" conditions for the purpose of evaluating the effectiveness of battery connection maintenance practices.

The procedures used by other facilities provided minimal guidance for the maintenance and testing of batteries. A cursory review found a lack of specific battery information such as number of cells, type of cell, manufacturer, specific gravity, etc. Other items that were often not given consideration are:

- requirement for periodic battery service test;
- requirement for periodic performance discharge test;
- well-defined housekeeping requirements;

- individual cell voltage measurements while on float charge;
- battery cell interconnection resistance measurements or alternatively, cleaning and retorquing instructions; and
- battery specific acceptance criteria.

The procedures and data sheets used for PM and testing of battery systems at most sites were generally found to have the same problems described in Section 6.1.5 of this report.

One procedure required a monthly equalizing charge of the battery. A monthly equalizing charge should not be necessary if the float voltage is maintained at the manufacturer's recommended values. An equalizing charge should be performed if individual cell voltages and specific gravity values deviate from one another significantly (manufacturers specify values for initiating an equalize charge). It should be noted that frequent equalizing is detrimental to battery life.

Another procedure gave instructions to measure specific gravity after adding water which, may be unnecessary and, could result in inaccurate readings due to insufficient mixing (it may be several days before an accurate measurement can be obtained). Another item covered adding an acid solution to batteries, which is not recommended, only water should be added. The addition of an acid solution could produce differences in cells and mask the identification of bad cells through measurement of specific gravity and individual cell float voltage. Consideration should be given to improving these kinds of instructions and procedures bringing them into closer consistency with available standards and manufacturer's recommendations.

At one site, the central organization responsible for battery system PM was not confident that they were aware of all site batteries requiring maintenance. The maintenance technicians would spend some of their spare time going through various facilities to "discover" whether additional batteries existed that should be receiving PM from their organization. Their list of site batteries has expanded using this technique. At another site, an important switchyard battery was not included on the list of batteries to be maintained by the maintenance group responsible for PM of all station service batteries. There appears to be a need to ensure that all batteries have been identified so that appropriate PM can be applied.

A program for training battery technicians is necessary to ensure battery system maintenance and surveillance is performed properly. One facility which has comprehensive procedures for battery maintenance and testing also has a program for qualifying individuals to perform battery maintenance and surveillance. This includes instruction by qualified trainers, actual performance of the maintenance and surveillance under the instructor's supervision, and certification of the trainee's qualification. For another site area, there was general maintenance training for personnel, but little specific training on batteries. One training form indicated that training consisted of reading a general procedure for battery maintenance/surveillance with a sign off to indicate the procedure had been

read. There appeared to be no requirement for any supervised "on the job" training by qualified personnel. There does not appear to be a uniform training program for battery maintenance/surveillance for all site areas. Consideration should be given to evaluation and upgrading of the battery maintenance/surveillance training program at all areas and of requiring maintenance personnel to be qualified. This training could perhaps be better accommodated at the site level for uniformity and consistency.

At another site, maintenance is done informally when the maintenance personnel are in the area. No records could be found for trending battery parameters although maintenance personnel stated they do check specific gravity, voltage and physical condition. There is also no schedule for replacement of batteries in UPSs or EDGs. No problems with batteries or battery chargers were on record though there were known to be failures of chargers. At another site, the procedure for battery maintenance endorsed IEEE STD-450-1987 monthly inspection requirements. However, it was not clear to what extent the standard is used and several parts of the procedure were missing. In addition, one part of the procedure allowed an equalizing charge voltage that could potentially damage components if applied for an extended period of time.

Another site had only one man assigned to battery maintenance and because he is sometimes assigned other work, battery maintenance has been delayed or not performed at all. The lack of consistent maintenance can result in batteries failing to perform their emergency/safety functions.

One site had a generic procedure for switchgear control power batteries, but without specific acceptance criteria and no requirement for any capacity test.

The AET found that significant improvement has been made in the battery maintenance and testing programs at some sites. However, it appears that the improved programs are not uniformly applied to all appropriate facilities. Significant improvements are needed in the battery maintenance and testing programs at other sites. Continued emphasis should be placed on the improvement of battery maintenance and testing programs at all DOE sites. This should include evaluation of programs to incorporate the maintenance and testing requirements of industry codes and standards, and records keeping for battery maintenance and testing. In addition, training programs should be evaluated to assure they include adequate classroom and supervised on-the-job training to qualify maintenance personnel on general battery maintenance procedures and on specific plant batteries.

At many sites, test records do not clearly demonstrate that the battery's capability and capacity is adequate for performing its design function. For important battery applications, a battery load profile should be developed and the procedures of IEEE 485 applied to assure proper sizing of batteries.

6.3.2 Battery Material Condition

A sample inspection of battery installations at several DOE facilities found a range of battery situations and conditions. At one site, which had

comprehensive procedures for maintenance and testing of batteries, the batteries inspected were generally clean and appeared in good condition. However, some of the battery rooms were excessively warm and did not seem to have adequate ventilation. Another facility at the same site had one battery room with excellent air conditioning, but other battery rooms that were uncomfortably warm. Some batteries were corroded and dirty and others were completely enclosed in a locked steel box with no visible means of ventilation.

The area directly outside the battery room in the basement of one facility contained heat generating equipment, including steam lines and an electrical substation. This area had forced air ventilation, but no air conditioning. A thermometer mounted on the side of one battery cell indicated a temperature of 86 degrees Fahrenheit. The charger for this battery was mounted on the wall of an adjacent room in the facility basement. The wall and charger were severely vibrating because of operating ventilation system equipment located in the room. At another site, a local thermometer indicated a room temperature of 95 degrees Fahrenheit. The battery shared the room with an electric boiler, an air compressor, electrical switchgear, and other equipment. The batteries at one facility at another site were very warm to the touch and the electrolyte levels in most of the 90 cells were low; some were far below the low-level mark, and one cell with a cracked case was dry. The charger output voltage was significantly higher than would be expected for the battery float charge.

Individual cells were not uniquely numbered in many battery installations, making surveillance measurements more difficult and susceptible to errors. Most battery racks appeared to be well grounded, although a few were not. Many battery racks did not appear to be seismically qualified. The most common problem regarding battery installations was high ambient temperatures, often near or above 90 degrees Fahrenheit. The material condition problems described for UPS batteries in Section 6.2.2 of this report were generally also found applicable to other battery installations.

A number of battery installations were found to be in good condition, clean with no visible signs of corrosion. However, others had conditions indicative of poor maintenance practices. Poor material condition often indicates the need for additional emphasis on maintenance programs. The AET believes that an evaluation of existing PM and testing programs for batteries and the significance of many battery installations would show that improvements are necessary to ensure battery system reliability commensurate with mission and safety objectives.

6.4 Automatic Transfer Switches

The ATS devices are used in power systems to transfer buses and their associated loads from one power source to another. The ATSS are routinely used at DOE facilities to transfer from the normal power source to the standby or emergency power source upon loss of the normal source. The ATSS are widely used in UPS and EDG applications. Although ATS devices generally improve the reliability of power to a facility's more critical loads by allowing either of two sources to supply power, their failure to

successfully perform the transfer function upon loss of normal power has the same effect as failure of the emergency source itself. An ATS failure usually means that neither source can supply power to the intended loads. For this reason, ATSs need proper maintenance and testing to ensure their availability and capability to perform the transfer function when needed.

6.4.1 ATS Testing & Maintenance

The AET reviewed the testing and maintenance activities at several sites with the following results.

Preventive maintenance for the ATS in an UPS system at one facility was performed by the equipment vendor. The PM activities were found to be technically accurate and sufficiently comprehensive. These included such tests/checks as pre-maintenance voltage/current values, verifying accuracy/operability of all front panel meters and indicators, checking the quality of critical electrical terminations, and measuring characteristics of static transfer switch operation using an oscilloscope. However, it appears that the transfer switch may have been tested incidentally because it was a component of the UPS system supplied by the vendor. At another site, the AET found a good and improving maintenance program for ATSs. However, a review of PM records revealed that the annual test for one ATS, which had been signed off as being completed, had actually never been performed. The review of procedures used for EDG load testing at several sites indicates that capability of the EDG to connect to facility loads via the ATS is often not verified. The operating and technical support staff for one facility indicated that the ATS was a highly reliable piece of equipment and needed no further attention.

At another site, the AET learned of one ATS failure where the ATS connected both power sources together and caused damage to an EDG, and another where a failure at the ATS output terminals caused loss of normal power and precluded access to backup power. However, the technical staff at another facility on the site were unaware of any ATS failures, either at their facility or at other facilities. From the walkdowns and discussions with facility personnel, it appears that a PM program is needed for ATSs. At other sites visited, the AET found no indication that a PM or testing program was in place for ATSs.

In summary, there is a general lack of PM and testing programs for ATSs. In view of the widespread use and importance of these devices in providing emergency power, the AET believes that consideration should be given to developing and implementing a PM and testing program for ATSs based on manufacturer's recommended practices.

6.4.2 ATS Material Condition

The AET did not specifically address the material condition of ATSs except to the extent they were included in the assessment of the EDGs and UPSs. The material condition of EDGs and UPSs are discussed in Sections 6.1.6 and 6.2.2 of this report.

7.0 ORGANIZATIONAL STRUCTURES & INTERACTIONS

7.1 Maintenance Organizations and Equipment Ownership

The AET reviewed the roles and responsibilities of site organizations involved with maintenance of E&BP system equipment. The AET also attempted to gain an understanding of how the various organizations interact, and how related institutional and programmatic issues affected the quality and effectiveness of maintenance activities. It was apparent that a positive attitude and desire exists with regard to maintaining high E&BP system reliability at all sites visited by the AET. However, the AET found situations at many sites where (1) multiple organizations each had some involvement in testing and maintenance of the same equipment, and (2) identical or similar types of equipment at different site locations were being independently maintained by separate organizations. The division of maintenance responsibilities between multiple organizations appeared to create coordination and communication problems, made it difficult to effectively monitor, trend, and evaluate E&BP system performance, and caused confusion over who is responsible for the overall reliability of E&BP systems. Some examples of situations found at a few of the sites are presented below.

At one site, the AET was informed that as many as seventeen different organizations were performing PM. Each major programmatic division includes a group responsible for division maintenance. A central site services organization is responsible for operating some power equipment and providing some equipment maintenance, and operates between 30 and 40 percent of the backup power systems, such as EDGs and station batteries. The central site services organization performs the maintenance on the mechanical engine portions of all EDGs. The maintenance on the generator, the starting system and other support systems, and instrumentation and controls is performed by the programmatic divisions. At a typical facility, the large support power systems for the facility are operated by central site services personnel; other systems are operated by the programmatic operating organization. The technical content of the surveillance actions, periodic testing, and preventative maintenance is determined by facility technical support personnel. Those actions are then executed by the facility operations or maintenance personnel. Communications have at times been poor between maintenance groups with regard to coordinating maintenance work during outages. In one case, EDG maintenance was not performed during an outage. In other cases oil changes were made only one week apart. Efforts are being made to effect better coordination and cooperation among the different groups to schedule outages and perform maintenance more efficiently.

The technical responsibilities for UPSs and the associated batteries have been assigned to "system engineers" within the programmatic technical support organizations. However, industry standards and the experience of other organizations with similar equipment are typically not reviewed by the system engineers. This function might normally be performed by a central engineering staff responsible for developing and maintaining PM procedures. In the absence of central engineering support, the system engineers do the best they can to apply the maintenance practices recommended in vendor

technical manuals. The system engineers' involvement in E&BP system PM is usually considered of secondary importance to other assigned tasks (some system engineers indicated that they spend less than ten percent of their time working on their assigned system). In some cases, the system engineers have not received appropriate training. This type of organizational structure and assignment of responsibilities was found to result in widely varying degrees of surveillance, testing, and maintenance performed in similar service applications at the same site.

There are two groups at this site involved in performing battery maintenance: a site central group that performs service and performance discharge tests, and the programmatic division's facility related maintenance group that performs the more routine tasks such as weekly, monthly, quarterly and yearly surveillance and maintenance. The site central group does not routinely perform service and performance discharge tests on "facility" batteries, but will do so upon request.

At another site, there are four separate groups involved in testing E&BP systems: a site central maintenance group (responsible for maintenance of electrical and electronic equipment); a general plant services group (known as the "garage"); a central site superintendent's office; and the building managers. All E&BP supply maintenance is performed by the central maintenance group and the garage. With the possible exception of the superintendent's office, the PM procedures used by these groups are provided by the central maintenance group. The superintendent's office verifies operability of equipment important to life safety, including criticality alarm systems and the associated generators providing backup power (approximately 13 generators). The central maintenance group believes that the generator tests performed by the superintendent's office are start and run tests similar to theirs. However, there is no feedback received concerning the test results unless corrective maintenance is required. The central maintenance group indicated that they were looking at consolidating the tests to ensure consistency, better monitoring of test data, and to prevent unnecessary duplication. At another site, the central maintenance organization responsible for all repair activities, but only for a portion of the periodic testing, complained that they were not made aware of abnormal equipment operating conditions that would typically require their attention (e.g., unusually long periods of operation, excessive discharges, or abnormal operating characteristics or stresses).

The AET believes it is essential that E&BP system equipment be assigned an owner having overall responsibility and authority for ensuring that the equipment performs adequately and that reliability and availability are maintained at acceptable levels. The AET attempted to identify the organizations and personnel having "ownership" responsibility for E&BP system equipment. However, ownership responsibility has often not been assigned to specific individuals. It was apparent at several sites that no one group is tasked with, and responsible for, the maintenance and upkeep of the EDG systems at a given facility. There are a number of contributing organizations including mechanical maintenance (garage), electrical maintenance, utility operators, facility managers, and most recently, systems engineers, who all have "bit parts" of the overall care and upkeep

of the EDGs. At one site, the EDGs used in one specific program/mission application were the responsibility of one organization, while all other standby EDGs were maintained by several different organizations. The consolidation of maintenance tasks under a single organization may significantly improve the cost effectiveness of PM activities, help to optimize equipment performance, and result in better planning and eliminate duplication of activities.

The AET found that equipment "ownership" is not a well defined or understood concept, and varies from site to site and facility to facility. In one case, the system or "cognizant" engineer was said to "own" the equipment; in other cases, two different organizations thought they could probably be considered the owners; in another case, it appears to be the user, however, it is not clear what the user does in relation to maintenance and test activities; in another case, the "owner," who was also the user, was responsible for assuring proper maintenance and operation; at another site, it was not clear who had ownership, frequently resulting in difficulty determining who is responsible for maintenance activities; in other cases, E&BP equipment is owned, operated, and maintained by the facility.

From discussions with maintenance personnel at a couple of sites, it became evident to the AET that E&BP system equipment had been without an overall system sponsor in the past. At one site, this was reflected by the lack of care and attention the equipment had received over the years; the M&O contractor had documented the need to improve the degraded condition of equipment. This site has recently placed the management of the E&BP supplies under one organization. This organization was given ownership because they have the most E&BP systems requiring maintenance. Other organizations provide support in the testing, maintenance, QA, and analysis of the systems. The division of responsibilities and authority for E&BP system PM were in the initial stages of development and had not been fully established.

In summary, maintenance of E&BP system equipment is often performed by a combination of various organizations that appear in part to be the result of an infrastructure which has developed over the years. These organizations are frequently without clearly defined lines of authority and responsibility, and the interfaces between them are usually not well controlled. This has resulted in a fragmented approach to maintenance with widely diverse PM practices on similar equipment. This approach is clearly not the most efficient or cost effective method, and is not ideal for achieving desired E&BP supply performance and reliability.

A strong site-wide maintenance program which establishes clearly defined roles and responsibilities and promotes the use of adequate resources for maintenance should be implemented as recommended in DOE Order 730.4A. Various approaches can be taken to implement an effective maintenance management program. The following discussion is not intended to endorse or prescribe a particular approach, but rather to point out some of the advantages of certain approaches and to provide information concerning approaches that have proven effective.

The AET believes a part of the organizational problem is the need to define the concept of ownership and its associated responsibilities, and to establish clear lines of authority and responsibility for the maintenance and operation of E&BP system equipment. Some sites were looking at the ownership issue and trying to decide the best approach. The AET suggests the following as guidance in establishing such a definition: the "owner" is the one defined as having both possession of the equipment and control over its operation. Therefore, in most applications, the owner of the equipment would be the program organization in charge of conducting facility operations. The owner should be responsible for, and held accountable for, assuring that appropriate maintenance and testing activities are performed to sustain equipment performance and reliability. The assignment of ownership should, as much as possible, be at the facility/user level. It is important that all E&BP equipment be assigned ownership so there is no doubt as to who is responsible for the operation and maintenance of specific E&BP equipment.

A primary strength of a facility is its ownership of the equipment, including E&BP supplies, that supports its operation and is vital to the health and safety of its workers. This ownership and its associated responsibilities should be taken seriously. The equipment owners should have control over their equipment at all times. They should monitor equipment status, verify that the equipment is operable and ready to perform when required, operate equipment as necessary, ensure that equipment performance is acceptable, and ensure proper scheduling and completion of PM, corrective maintenance, and surveillance activities (including those performed by outside organizations). The owner should verify that maintenance activities are appropriate, do not cause the facility to operate outside of TSRs relative to the E&BP systems, and will not compromise the facility safety envelope (i.e., the owner should ensure that the facility authorization basis remains valid).

Management at the site and facility level should, using a graded approach, ensure that maintenance programs effectively include E&BP equipment. Advantage should be taken of the complementary strengths of both central (site) and program (facility) organizations. A central maintenance organization can help facilities meet their obligations as equipment owners by providing experienced personnel dedicated to performing PM tasks. This is especially true for work that involves extensive or complicated maintenance and testing activities, or collection of data for analysis of equipment performance. Significant improvements in E&BP system performance have been realized at some sites by having maintenance work performed by central maintenance organizations. Advantages to having maintenance performed by site central organizations versus individual program, area, or facility organizations at a multi-facility site include:

- being able to apply the knowledge and experience gained from working on identical or similar pieces of equipment at other locations around the site, and providing a single point of contact for engineering support organizations that analyze E&BP system performance to identify and resolve potential problem areas before they affect equipment operability;

- preparation of the preventive and corrective maintenance testing requirements and associated procedures for all site E&BP equipment to ensure consistent high quality across the site (e.g., establishing PM and test intervals, implementation of good engineering practices established in industry codes and standards, incorporation of manufacturer recommendations into procedures, recording the correct type of data for trend analysis, etc.);
- managing site maintenance and surveillance activities through a computerized work management system that tracks PM work activities, maintains task specific work packages and procedures, and allows for easier implementation of DOE Order 4330.4A, "Maintenance Management Program;"
- development of comprehensive training and qualification requirements for maintenance personnel (these requirements would have to be tempered by any necessary facility specific training and certification requirements);
- performing maintenance activities in a more efficient and cost effective manner (e.g., in terms of personnel resources, spare parts inventory, management of outside maintenance contracts, training expenses, etc.);
- Performance of infrequent, complicated maintenance and testing activities for which it is difficult for the individual facilities to maintain training and proficiency.

In order for a PM program to be effective, there must be mutual respect and cooperation between the maintenance support and programmatic organizations. The facility (owner) should work closely with the central maintenance organization, where used, and the engineering support organization, as necessary, to verify that equipment is being adequately maintained and performing acceptably. The maintenance organization might conduct the test/maintenance activity, connect and remove test equipment, take necessary readings, and document and maintain associated records, but the program (facility operating) organization would be responsible for ensuring that PM is performed, operate facility equipment as necessary during testing, and closely monitor the activity and results and determine the impact on the safety and productivity of their operations. The owner is responsible for removing equipment from service, implementation of an effective lockout and tagout program, and placing the equipment back in service.

Although maintenance and testing of E&BP systems is frequently a joint effort by the central maintenance organization and individual facilities, it is recognized that there may be unique situations where it may not be practical to use a centralized maintenance organization. Where individual facility or program owners do all PM and surveillance testing of their E&BP equipment, it is recommended that these activities be closely coordinated with the central organization, and that consideration be given to using on-site (i.e., at the facility) system engineering expertise that is matrixed

from the central organization to ensure consistent and proper care of the equipment.

7.2 Management Support of Maintenance Activities

The most successful maintenance programs for E&BP system equipment were found where a clear commitment from site upper management exists in terms of policy and direction along with allocation of resources. In some organizations, insufficient personnel were assigned to perform maintenance and surveillance activities. At one site, monthly battery PM for 76 battery systems was performed by two "one-man crews." Each month, the two maintenance technicians would start at the top of their list of assigned batteries and attempt to work their way down, but were often pulled off to perform other "more important" tasks (e.g., supporting tiger team activities). There should be at least two technicians available for working on energized electrical systems for personnel safety reasons.

Similar situations were found at other sites. At one site, the temporary reassignment of maintenance personnel to other tasks resulted in decreased surveillances (e.g., performing quarterly tests only once or twice a year). At another site, PM procedures had not been developed for all equipment, and despite DOE audits of the maintenance program that identified the need for more staff and funding, and criticized past practices of "run-to-failure" and "crisis maintenance," the level of funding for PM activities was subsequently cut. At some sites the AET was left with the impression that the amount of attention given to PM of E&BP system equipment was disproportionate to the cost value of the equipment and its importance to mission and safety objectives. Experience in the commercial nuclear industry has shown that the costs of implementing a proactive maintenance program are more than offset by savings in lost production time and equipment repairs.

Facility managers should encourage, support, require, and be held accountable for ensuring that E&BP equipment is properly maintained. However, the AET found many examples of failure of facility management to support maintenance and surveillance activities for E&BP equipment, including (1) not allowing maintenance activities to be scheduled or performed for fear of interference with facility operations, and (2) altering the E&BP system configuration prior to testing to "reduce the impact" on facility operations (a common example is stripping facility loads prior to EDG load testing). Altering the E&BP system configuration prior to testing can invalidate or skew the test results such that they no longer demonstrate capability of the E&BP system to perform in response to actual loss of power demands. Statements by maintenance personnel lead the AET to believe that these may be significant problems.

Facility managers must sometimes temporarily suspend process operations to allow certain E&BP supply surveillance test and maintenance activities. In the past they have been reluctant to stop facility operations for maintenance work. Maintenance personnel at several sites indicated that maintenance on E&BP system equipment had sometimes been delayed or canceled because the facility would not release the equipment for maintenance. Some

facilities are very production oriented, and have severely pressured maintenance organizations into minimizing facility downtime. At one site, the maintenance department was not allowed to test the ATS at a nuclear facility; the EDG started as designed during a subsequent loss of power event, but the ATS failed to switch-over to supply EDG power to facility loads; the facility did not report the ATS failure to the maintenance department.

For maintenance programs to be effective, the facility program and site maintenance organizations must work together closely to achieve the common goal of optimum reliability of E&BP equipment. The benefits of well maintained E&BP systems include higher reliability (greater assurance that the system will function as designed, resulting in proper facility response to loss of power demands and less downtime) and fewer repairs. Facility program organizations must recognize the need for and benefits of preventive maintenance and testing programs, assume the lead role in planning and scheduling maintenance activities, and cooperate with maintenance organizations performing the work. The maintenance department must be sensitive to facility process demands, attempt to best schedule activities to minimize impact on facility operations, and not expect facility equipment to be "turned over to them" for PM. Maintenance organizations at some sites have recently taken steps to improve relationships with facility and program personnel. This has led to better understanding and cooperation, easier access to equipment for PM, and improved E&BP system reliability.

The AET recommends that DP issue a SIL that: (1) documents DOE's policy concerning the need for implementing an effective Maintenance Management Program in accordance with DOE Order 4330.4A that ensures high reliability of equipment important to the safety of workers, the public, and the environment; (2) addresses the need to establish overall organizational responsibilities and authorities for maintenance of E&BP system equipment and for ensuring that E&BP system reliability and availability are maintained at acceptable levels; and (3) emphasizes the need for M&O contractor upper management commitment and support to maintenance organizations responsible for E&BP equipment, including sufficient funding and cooperation from site program organizations and facility managers.

7.3 Engineering Support and Configuration Control

The AET performed a cursory review of work control systems used to manage PM activities related to E&BP equipment at several sites. Work control systems at many sites were found to be evolving or changing at the time of the AET review, largely because of recent efforts to implement DOE Order 4330.4A, "Maintenance Management Program." Progress is being made at all sites in this area. Implementation of DOE Order 4330.4A will improve the quality of work control and management system planning, scheduling, and coordination functions. Although improvements are being made, it should be noted that many of the work control systems are in the initial stages of development, and full implementation of DOE Order 4330.4A will not be completed for several years at many sites. For some PM activities, revised work packages have not been developed or are being developed as maintenance comes due. One area of concern is that it is not always clear what organization has the

responsibility for determining which equipment is to be maintained, how it is to be maintained, and on what basis. These important responsibilities must be clearly defined, and maintenance guidelines prepared for various equipment types and applications, to ensure consistency, proper use of resources, and inclusion of the appropriate equipment in PM programs. The DOE Order 4330.4A states that:

"for nuclear facilities, the structures, systems, and components to be maintained, the types of maintenance to be conducted, and the frequency of those maintenance actions shall be determined by a systematic analysis..."

Many facility and site maintenance organizations use some type of computer based system to provide periodic printout of schedules of the work to be performed. At least one site was attempting to centralize this function. Most maintenance organizations had developed a system for maintaining and upgrading work packages and procedures that often included some form of quality checks to ensure they adequately accomplish their intended functions. Some sites use organizational sign-offs to ensure better coordination of activities and ensure proper movement of work packages through the organization. Improvements at one site included restructuring maintenance organizations and identification of required interfaces with support organizations for functions such as quality control and engineering analysis.

At most sites, engineering support is available for working on PM work packages and procedures and is sometimes used effectively. At one site, each program area has an engineering group that provides technical support to maintenance personnel when necessary. The area engineering support group assigns individuals to provide the technical support for a facility. For example, in relation to battery maintenance, these individuals would be involved in battery problems not resolvable by the maintenance group and would determine if a battery should be replaced and may perform sizing calculations. The engineering support personnel also review the test data and non-conformance reports and generate work requests for battery replacement.

However, at many sites, the engineering organization is not routinely involved in the review of test data and results. The AET identified this as an area needing improvement. As discussed in detail in Chapter 6, record keeping practices and available documentation concerning E&BP supply performance history has been relatively poor at most sites. The data which is available, usually kept by facility engineers or groups responsible for E&BP system maintenance, is typically never reviewed by the engineering organization. The DOE Order 4330.4A requires that maintenance programs include:

- *mechanisms for feedback of relevant information, such as trend analysis and instrumentation performance/reliability data, to identify necessary program modifications;*

- *provisions for identification, evaluation, and correction of possible component, system design, quality assurance, or other relevant problems;*
- *performance indicators and criteria to be used to measure equipment, systems, and personnel effectiveness in maintenance activities.*

A well defined interface between the maintenance and engineering organizations, including clear definitions of roles and responsibilities, is needed to effectively implement these maintenance program elements. Improvements have been made at some sites in the areas of engineering support and configuration control with the creation of the "System Engineer" position and with the implementation of computerized work control systems. Continued emphasis is needed in both these areas for developing strong engineering support and control of equipment records.

Another area that requires further attention is the control of E&BP system configuration documents. Load lists, panel schedules, and drawings reviewed by the AET were rarely accurate (e.g., loads were shown that had been deleted). At several sites there was a significant time lag between when changes are made to the electrical distribution system configuration and when revised drawings that accurately reflect the installed configuration are received by the facility engineers. Huge backlogs often exist, and therefore the latest version of drawings are often outdated. At one site, it appeared to the AET that adversarial relationships had developed between facility or site engineering groups and groups responsible for drawing updates, adding to the problem. The best available information was often uncontrolled drawings that had been marked up by facility engineers to reflect the existing configuration to the best of their knowledge. Although these drawings are uncontrolled and may not have been reviewed by plant engineering for accuracy, they appear to be the best drawings available, and are routinely used.

The accuracy of as-built drawings was identified as a deficiency at practically all sites. The drawings at several facilities were described as being basically useless. Configuration management problems concerning inaccurate drawings were well recognized by facility staff. It is the understanding of the AET that problems regarding drawings that do not accurately reflect existing installations has been a common finding from other review efforts (e.g., tiger team assessments).

8.0 FINDINGS & RECOMMENDATIONS

8.1 Findings

The following findings are generic to more than one site, but are often not applicable to all sites that participated in the review. Problem areas identified by the AET were often already known to the Management and Operating (M&O) contractors and DOE Operations Office, Area Office, and Site Office personnel. The AET saw progress being made at all sites to rectify many of the shortcomings that exist. The findings do not always identify a problem. Some of the findings are observations that clarify and provide a basis for the recommendations that follow:

1. At the sites visited by the AET, there are in excess of a thousand backup power supplies (i.e., diesel generators, uninterruptible power supplies, and batteries), approximately one third of which provide backup power to equipment that appears to be important to safety (e.g., criticality alarm systems, radiation monitoring equipment, confinement system ventilation exhaust fans, emergency lighting, security systems, and fire alarms).
2. With the exception of some DOE reactor facilities, there are significant differences between EDGs at DOE facilities and EDGs at commercial nuclear power reactors. The EDG installations at DOE facilities are, in general, much smaller and less complex. These designs typically result in easier starts, and are less prone to failure after start. Differences exist in preventive maintenance and surveillance practices because of the smaller and simpler EDG designs. Therefore, it is not always appropriate to apply Nuclear Regulatory Commission (NRC) criteria for EDGs used in the commercial nuclear power industry to EDGs at DOE facilities. In addition, maintenance recommended by the EDG vendor may not be adequate for EDGs used in applications as standby emergency power sources (e.g., a preventive maintenance activity whose frequency is based on the number of engine hours elapsed since the activity was last performed may not be adequate because of the long time periods required to accumulate hours). The design basis for each EDG application should be thoroughly evaluated to determine the appropriate criteria and practices to be included in preventive maintenance programs.
3. The AET observed varying degrees of understanding and application of good engineering practices for operation and maintenance of E&BP equipment. The AET found areas of technical expertise and program excellence at some sites that could benefit other sites. The AET found many examples of similar equipment types and functions where shared information such as design features, procedures, maintenance practices, and lessons learned from operating experience would be useful to personnel responsible for E&BP system design, operation, and maintenance, and could lead to increased E&BP supply reliability. However, there is little communication among DOE sites concerning E&BP systems.

4. The review of load dispatch center logs showed that site distribution system power losses affecting one or more facilities are not uncommon. The loss of normal power to a given facility that challenges the facility E&BP system is clearly a credible occurrence and should be expected. Common causes for loss of normal facility power are inclement weather (rain, snow, sleet, high winds, and lightning), large birds, and personnel error, often involving movement of heavy equipment (e.g., cranes and trenching/drilling rigs). The most common cause for loss of normal power is lightning.
5. Common perceptions among M&O contractor personnel are that (1) a complete loss of electrical power will not result in adverse safety consequences, and (2) that the impact (costs and delays) on DOE programs caused by E&BP supply failures is a larger concern than the potential safety consequences to workers, the public, or the environment. The AET did not find documentation to substantiate these perceptions. The safety implications of E&BP supplies at DOE facilities and their contributions to overall risk reduction are not well analyzed and do not appear to be fully understood. The AET did find E&BP supplies used in applications where the consequences of failure do not appear to be significant from a safety perspective.
6. There is little documentation or analysis concerning the safety significance of E&BP supplies. The SAR analyses typically assume high reliability and availability of electric power. The analyses are often outdated and do not address the potential worst-case consequences that could be realistically expected if E&BP supplies fail to function as designed. Worst-case scenarios involving a complete loss of electrical power and an accident (such as fire or unplanned release of toxic or radioactive materials) are not formally analyzed to demonstrate that either the scenarios are not credible (i.e., are extremely low-probability events), or that the consequences are acceptable. The safety significance of E&BP supplies needs to be fully understood so that those supplies important to safety are identified, classified, recognized, and treated as such by designers, users, and maintainers.
7. Failure modes and effects analyses (FMEAs) for electrical systems seldom analyze all credible component failures such as E&BP supplies and automatic transfer switches. There are few applications that use redundant E&BP supplies or that have a diverse alternate source. Redundant E&BP equipment that is provided is typically treated as being independent, even though the redundancy is often compromised by common dependencies and is susceptible to single failures.
8. The reliability of E&BP supplies should improve through the implementation of DOE Orders and ongoing programs to improve SARs, technical safety requirements (TSRs), configuration management, and procedures. However, improvements are to be implemented using a graded approach based on the safety significance of specific E&BP supply applications. The AET believes that the safety significance of E&BP supplies needs to be better understood to ensure effective graded approach implementation of DOE Orders.

9. The AET found a general lack of proper configuration control at most sites as evidenced by failure to maintain adequate E&BP system information such as accurate up-to-date drawings and records of loads assigned to buses and power sources. In a few instances, E&BP equipment was not properly identified. Problems resulting from improper configuration control include potential overloading and malfunctioning of equipment important to safety, and safety hazards to personnel maintaining or modifying E&BP system equipment. The lack of unique identification, or omission of such equipment from site equipment lists, may result in E&BP system components not being evaluated for safety classification and not being included in a maintenance program.
10. The AET believes that, in general, E&BP supply reliability can and should be improved at most sites. Using the limited amount of data available concerning EDG responses to tests and actual demands, it appears that EDG reliability is often near or above 90 percent. However, accurate determinations of E&BP system reliability can not be made without substantial improvements in the programs for collection, analysis, and trending of data relating to system failures, down-time, and performance. The areas needing improvements include data quality, quantity, and documentation. Implementation of DOE Order 4330.4A, "Maintenance Management Program," should result in improved monitoring, data collection, performance analysis, maintenance, and reliability of E&BP equipment. Some DOE sites have made significant progress toward implementation of this Order.
11. Contractor maintenance organizations often have not assigned overall responsibility and authority to specific individuals for ensuring that E&BP supplies perform adequately, and that reliability and availability are maintained at acceptable levels. Maintenance, testing, and repair of E&BP supplies is often performed by various independent sub-organizations. The lack of clear lines of authority and responsibility for maintenance activities has affected E&BP system performance.
12. The most successful maintenance programs for E&BP system equipment were found where a clear commitment from site upper management exists in terms of policy/direction and allocation of resources. The AET found many examples of failure of facility management to support maintenance and surveillance activities for E&BP equipment, including (1) not allowing maintenance activities to be scheduled or performed for fear of interfering with facility operations, and (2) altering the E&BP system configuration prior to testing to "reduce the impact" on facility operations (a common example is stripping facility loads prior to EDG load testing). Statements by maintenance personnel lead the AET to believe that these may be significant problems. Altering the E&BP system configuration prior to testing can invalidate or skew the test results such that they no longer demonstrate capability of the E&BP system to perform in response to actual loss of power demands. Comprehensive exercise of all system components during testing is necessary to discover and correct problems or failures that may have

occurred so that the system will respond as intended during actual demands.

In some organizations, there are insufficient personnel resources available to adequately perform maintenance and surveillance activities. This has sometimes resulted in missed surveillances. In one case, a single person was responsible for maintaining all batteries at one site and due to temporary assignment to other tasks, maintenance had been delayed or not performed. Standard engineering practice requires at least two people to work together when conducting electrical maintenance to ensure personnel safety when working with potentially dangerous equipment. Inadequate personnel resources may contribute to the poor material condition of equipment found in several instances.

13. The material condition of E&BP equipment varied from site to site and from facility to facility. Most E&BP installations were found in good condition, with equipment in a clean and well-kept state. However, there were a number of instances of poor equipment condition (degraded or missing parts, lack of cleanliness, oil leaks, corrosion, etc.) and adverse environmental conditions.
14. Data sheets used to record maintenance and surveillance activities often did not (1) include sign-off spaces for critical steps, (2) indicate specific parameters and their normal ranges to allow verification of proper operation, (3) provide instructions for what constitutes a failure or what to do in case of a failure, or (4) record as-found/as-left conditions, root cause information, or meaningful operating data for observing trends and anticipating failures. In some instances a significant amount of testing was done but no records were kept.
15. The AET found relatively few problems with EDG system engines or generators. The EDG support systems (i.e., starting system, fuel system, cooling system and lubrication system) and associated electrical equipment (e.g., transfer switches, circuit breakers, interlocks and controls) were larger contributors to EDG system failure. Problems associated with batteries in EDG starting systems were the dominant contributor to EDG failures. Although significant improvement has been made in battery maintenance and testing programs at some sites, battery maintenance and surveillance programs at many sites were found to be weak, and often did not conform with current standard industry practice.
16. The EDG systems are often not equipped to readily allow performance of load tests. The EDGs at DOE facilities are, for the most part, tested at or near no-load conditions which does not demonstrate capability of the machine to perform acceptably on an actual demand. No-load or light-load operation does not fully test vital equipment and functions such as the excitation system, the response of the speed control (governor) under load, the load carrying capability of the generator, protective trip/alarm circuits, or switchgear. In addition, no-load or

light load operation causes detrimental effects such as: (1) build-up of deposits on cylinder walls, valves, piston rings, etc. that can lead to mechanical failure, and (2) buildup of deposits in the exhaust system, potentially resulting in fire.

17. At many sites there was either no program for preventive maintenance of UPS systems, or maintenance and testing practices were not consistent with industry standards. Maintenance for UPSs is inconsistent among sites and among facilities at a given site. Of particular concern was the number of UPS installations exposed to detrimental environmental conditions, specifically high ambient temperatures. Routine preventive maintenance and maintaining equipment installations in accordance with manufacturers' specifications is paramount to reliable operation of E&BP equipment.
18. The AET found inconsistent battery system maintenance and testing practices between sites and between facilities at a given site. Sites often did not maintain records to demonstrate that battery capacity is adequate to supply connected loads for the required duration. In addition, inconsistencies were found in the supervision and training of personnel responsible for conducting battery maintenance.
19. The ATSS are widely used in UPS and EDG applications. The failure of an ATS to perform its design function of power transfer during a loss of normal power condition has the same effect as failure of the emergency source itself. Failures of ATSS have resulted in loss of both the normal power source and its associated E&BP supply. The AET found a general lack of preventive maintenance and testing of ATSS at DOE sites.
20. The AET found instances of incomplete post-maintenance testing and failure to require or perform post-maintenance testing. Post-maintenance testing is necessary to assure that the maintenance activity has been properly implemented and is effective, and has not induced other failure mechanisms.
21. The quality of data being input to the ORPS for E&BP supplies is often poor; many of the reports reviewed by the AET were inaccurate, missing relevant information and/or contained extraneous information. The causes given for failures were sometimes incorrect, partially because of the lack of involvement of technical experts in the reporting process. Additionally, the AET became aware of a number of failures that were not reported.

8.2 Recommendations

1. Conduct a workshop on emergency and backup power supplies for DOE Headquarters, Operations Office, and Contractor personnel responsible for the design, maintenance, and operation of E&BP equipment. The purpose of the workshop would be to establish and promote communications and sharing of information and technical expertise between DOE sites regarding operating experience, effective programs

and practices, solutions to problems, and methods for improving the performance of E&BP supplies. The workshop should provide the findings and recommendations of the AET review of E&BP systems, and should include presentations from E&BP equipment vendors on recommended maintenance practices. The workshop should stress the importance of understanding the safety significance of E&BP supply applications, provide guidance on how to analyze and document the safety significance of E&BP supplies, and emphasize the need for E&BP supplies important to safety to be identified, classified, recognized, and treated as such by designers, users, and maintainers.

Status of Recommendation: Implementation of this recommendation is complete. A workshop on emergency and backup power supplies was held in Albuquerque on June 8-10, 1993. The workshop was jointly sponsored by DB 9 and the Office of Engineering and Operations Support (DB 62).

3. Require a formal analysis of loss of normal facility power in conjunction with single failures within the emergency/backup power system for Nuclear Hazard Category 1 and 2 Facilities, as defined in DOE Standard 1027-92 "Hazard Categorization and Accident Analysis Techniques for Compliance with DOE Order 5480.23, Nuclear Safety Analysis Reports." The loss of power analysis should address the probability and consequences of E&BP system failures and should identify equipment and personnel actions necessary to ensure protection of workers, the public, and the environment. The level of detail required and magnitude of resources expended for the analysis would be determined using a graded approach (i.e., would be commensurate with a facility's relative importance to safety, environmental compliance, safeguards and security, programmatic significance, and/or other facility-specific requirements). The analysis results should be formally documented and updated as necessary to reflect current facility hazards and the E&BP system configuration.

Status of Recommendation: This recommendation is being considered by DP-62 in their ongoing activities to provide guidance concerning analyses required to satisfy the requirements of DOE Order 5480.23, "Nuclear Safety Analysis Reports."

4. Promote maintenance and surveillance practices for E&BP system equipment consistent with accepted good engineering practices embodied in industry standards, and provide guidance on how to monitor, assess, document, and trend equipment performance for the purpose of maintaining E&BP system reliability and availability at acceptably high levels. This guidance should include standard definitions for use throughout the DOE complex concerning what constitutes: (1) E&BP system operability, (2) successful E&BP system operation, and (3) E&BP system failures, including what types of failures should and should not be reported in accordance with DOE Order 5000.3B, "Occurrence Reporting and Processing of Operations Information." The guidance should include the information to be recorded on data sheets used to document maintenance and surveillance activities.

Status of Recommendation: This recommendation is being implemented by DP-62 through their effort to issue a Standard, entitled "Backup Power Supplies For DOE DP Facilities." The Standard, which is currently in draft form, consolidates accepted maintenance and surveillance practices for E&BP system equipment from a number of industry standards, and provides guidance concerning monitoring, recording, and assessing E&BP system performance. The guidance provided in the standard is not intended as requirements, but rather as methods and approaches that are consistent with accepted industry good engineering practices, and which should be considered to achieve E&BP system conformance with DOE Orders.

5. Issue a DP Safety Information Letter (SIL) that: (1) documents DOE's policy concerning the need for an effective "Maintenance Management Program" in accordance with DOE Order 4330.4A that ensures high reliability of equipment important to the safety of workers, the

public, and the environment; (2) addresses the need to establish overall organizational responsibilities and authorities for maintenance of E&BP system equipment and for ensuring that E&BP system reliability and availability are maintained at acceptable levels; and (3) emphasizes the need for M&O contractor upper management commitment and support to maintenance organizations responsible for E&BP equipment, including sufficient funding and cooperation from site program organizations and facility managers.

Status of Recommendation: This recommendation is being reviewed by the DP staff for appropriate action.

6. Although some facility electrical distribution system designs include redundant EDGs and/or feeder circuits for providing power to safety related loads (e.g., building ventilation system exhaust fans), there are often single failure points in the designs (e.g., ATSS) that can prevent these loads from receiving power. For those applications where redundancy is provided to improve E&BP supply availability/reliability, but where single point failure vulnerabilities have been identified that can compromise the redundancy, determine if modifications to provide true redundancy of equipment for accomplishing safety functions are cost beneficial.

Status of Recommendation: This recommendation has been given to the BPWG for disposition.

7. Assess the need for design improvements to existing lightning protection circuits to reduce the frequency and duration of power losses caused by lightning at Nuclear Hazard Category 1 and 2 Facilities where electrical power is important to the health and safety of workers, the public or the environment.

Status of Recommendation: This recommendation has been given to the BPWG for disposition.

8. The following recommendations concern maintenance practices for E&BP equipment. The AET believes that existing industry standards (e.g., published by the Institute of Electrical and Electronics Engineers), DOE Order 4330.4A, "Maintenance Management Program," DOE Order 5480.23, "Nuclear Safety Analysis Reports," and current initiatives such as upcoming efforts to improve configuration management programs at DOE sites, should form the fundamental basis necessary to ensure the proper design, operation, and maintenance of E&BP equipment important to safety. The recommendations below provide additional specific considerations for improved E&BP system performance.
 - a. Develop and implement specific guidance for the design, operation, and maintenance of EDG starting system batteries and chargers to ensure reliable performance, including how to monitor and assess performance, and replacement considerations.

- b. Develop and implement specific guidance for performing EDG load tests consistent with manufacturer recommendations. Consideration should be given to improved EDG designs that facilitate load testing without the need to remove and reconnect cables.
- c. Review E&BP equipment installations to identify and correct deficient material conditions. Particular emphasis should be placed on verification that operating environmental conditions for UPS systems and electrical/electronic equipment (e.g., transfer switches, circuit breakers, monitoring and protective instruments and circuits) are consistent with the manufacturer's specifications.
- d. Incorporate the applicable maintenance and testing requirements and good engineering practices of industry codes and standards pertaining to batteries, including record keeping and trending/analysis of test and performance data in accordance with DOE Order 4330.4A. For important battery applications, a battery load profile should be developed and the procedures of IEEE 485 applied to assure proper sizing of batteries.
- e. In view of the widespread use and importance of automatic transfer switches (ATSs) in providing E&BP, develop and implement a preventive maintenance and testing program for ATSs based on manufacturer's recommendations.
- f. Review work control systems and procedures to ensure that post maintenance testing is required where necessary to demonstrate that maintenance or repair activities are properly implemented and effective, have not induced other failure mechanisms, and that equipment is properly returned to service.
- g. Training programs at DOE sites should be evaluated to ensure they include adequate classroom and supervised on-the-job training to qualify maintenance personnel on E&BP supply maintenance and surveillance procedures for specific plant E&BP equipment.

Status of Recommendation: This recommendation has been given to the BPWG for disposition.

APPENDIX A

ACKNOWLEDGEMENTS

The AET review of E&BP systems was conducted by DP-9. Rabi Singh, Director, Safety Diagnostic Division (DP-9.1), provided management guidance for the AET review. Rick Kendall, Supervisor, Safety Assessment Group (DP-9.12), provided technical and management direction for the on-site reviews and preparation of this report. Joe Golla, DP-9.12, was AET Team Leader for the on-site review at Richland and Tom Staker, DP-9.11, was Team Leader for the first on-site review at Savannah River. Rick Kendall was Team Leader for all other on-site reviews.

This report was developed from the individual site visit reports prepared by the AET members. These inputs were consolidated and coordinated by Jim Knight, SAIC, and Bill Gunther, BNL, who together developed the overall content and format of the report. Technical editing of the report was provided by Robin McCroddan, LLNL, Robin Thompson, EG&G, and Jeannie Shipley, DOE/DP-9. In addition to the individual inputs from team members, significant contributions were made by J.T. Beard, Engineering Consultant (Chapter 4); Bob Barter, LLNL (Chapter 5), and Ken Sullivan, BNL (Appendix B).

Sites Visited

The following sites participated in the AET review on the dates indicated.

Rocky Flats (RF), 9/30/91 to 10/3/91
Richland (RL), 10/7/91 to 10/10/91
Savannah River (SR1), 10/7/91 to 10/10/91, and (SR2), 9/14/92 to 9/18/92
Pantex (PX), 3/30/92 to 4/3/92
Los Alamos National Laboratory (LANL), 4/13/92 to 4/17/92
Oak Ridge Y-12 Plant (Y-12), 5/18/92 to 5/22/92
Nevada Test Site (NTS), 7/13/92 to 7/17/92

AET Members

The AET members are listed below. The on-site reviews in which each member participated are indicated in parentheses following their name.

J.T. Beard, Consultant to Sciencetech Inc. (RF/SR2)
Frank Black, DOE/SR (SR1)
Phil Chong, DOE/RF (RF)
Pat Daly, DOE/Y-12 (Y-12)
Jim DeLong, DOE/NTSO (NTS)
Karl Frazier, DOE/SR (SR2)
John Fredlund, DOE/DP-62 (RL/Y-12)
Dennis Galvin, DOE/DP-9.1 (SR2)
Joe Golla, DOE/DP-9.1 (RL/LANL/NTS/SR2)
Bill Gunther, BNL (PX/Y-12/NTS)
Mark Good, Consultant to LLNL (SR1)
Ned Hallein, DOE/DP-641 (PX)
Burt Hill, DOE/RL (RL)
Rick Kendall, DOE/DP-9.1 (RF/PX/LANL/Y-12/NTS/SR2)

Joe Kerby, DOE/AA (PX)
Chris Kimura, LLNL (PX/LANL/Y-12)
Jim Knight, SAIC (SR2)
Howard Lambert, Consultant to LLNL (SR1)
Vinh Le, DOE/DP-9.2 (RF)
Jim Osborne, DOE/DP-62 (SR1)
Dave Padilla, DOE/LAAO (LANL)
Deb Pal, LLNL (Y-12/SR2)
Jay Pape, DOE/AL (LANL)
Keith Parkkinson, Sonalysts (SR2)
Bill Pittman, LLNL (LANL)
Frank Reimann, DOE/SR (SR1)
Tom Staker, DOE/DP-9.1 (SR1)
Ken Sullivan, BNL (LANL/SR2)
Dominic Tondi, SAIC (RF/RL/Y-12/NTS)
Milton West, DOE/AL (PX)
Bob White, LLNL (PX/LANL/Y-12/NTS/SR2)
Mark Woodworth, DOE/SR (PX/NTS/SR2)

The AET wishes to especially thank the DOE Operations Offices, Area Offices, and Site Offices for their efforts and contributions in support of this review.

This report would not have been possible without the cooperation of M&O contractor and subcontractor personnel responsible for the design, operation, and maintenance of the emergency and backup power systems reviewed by the AET. The AET was impressed with their concern for the quality of maintenance activities and their knowledge of the systems and equipment involved. They exhibited a willingness to openly exchange information with the AET on the type and frequency of maintenance and test activities and areas where problems had been experienced, and provided suggestions for potential areas for improvement.

APPENDIX B

SUMMARY OF INDUSTRY/REGULATORY STANDARDS AND GUIDANCE

During the AET site visits, selected aspects of PM programs implemented for major components of E&BP system (EDGs, UPSs, and batteries) were observed and compared to existing standards, practices, and guidelines developed by the commercial nuclear industry. In general, the AET found that the use of industry standards in the formulation and implementation of PM programs for E&BP system equipment was inconsistent. Many notable differences were observed in the selection, use and application of industry standards among sites and, in certain cases, among different processing areas located at the same site. The AET recognizes that the E&BP equipment installed at DOE facilities is typically smaller in size, and has operating characteristics and performance missions that differ significantly from similar equipment used at commercial nuclear power plants. Nevertheless, the basic philosophies and practices promulgated by guidance documents and standards developed by the commercial industry (nuclear and non-nuclear) and equipment manufacturers remain applicable.

The following listing of industry standards and guidance documents is provided as a ready reference of information to assist persons responsible for the design, maintenance, and testing of E&BP equipment and in the formulation of associated programs, practices, and procedures. The key elements of these standards for each major component of the E&BP system are identified in a separate table at the end of this appendix.

B.1 Emergency Diesel Generators

B.1.1 NRC Regulatory Guidance

The PM programs employed by commercial nuclear power plants for EDGs were the subject of a 1984 study performed by the NRC. The NRC issued Generic Letter 84-15, "Proposed Staff Actions to Improve and Maintain Diesel Generator Reliability," to solicit comments for enhancing EDG reliability. The industry groups responding to this letter included nuclear utilities, nuclear industry engineering and standards organizations (such as the Institute for Nuclear Power Operations and the American Society of Mechanical Engineers), EDG manufacturers, and foreign EDG users. The large amount of data, comments and recommendations obtained from these diverse organizations were then reviewed in a separate study, NUREG/CR-4557, "A Review of Issues Related to Improving Nuclear Power Plant Diesel Generator Reliability." This investigation found that the establishment of a comprehensive PM program has broad documented support for assuring EDG reliability.

The NRC guidance for EDG selection, design, qualification, and testing is currently contained in three key documents: (1) Regulatory Guide 1.9, Revision 3; (2) Regulatory Guide 1.108, Revision 1; and (3) Generic Letter 84-15. Revision 3 to Regulatory Guide 1.9 was published in response to concerns related to the monitoring and maintenance of EDG reliability levels required by the Station Blackout Rule (10 CFR 50.63). The NRC Regulatory

Guides (Reg Guides) describe methods acceptable to the NRC staff for implementing specific parts of the Commission's regulations. Alternative approaches to the methods described in Reg Guides may be used provided they have an acceptable technical basis.

- **R.G. 1.9, Rev. 3:** "Selection, Design, Qualification and Testing of Emergency Diesel Generator Units Used as Class 1E Onsite Electric Power Systems at Nuclear Power Plants." - Endorses and supplements IEEE Std 387-1984.
- **R.G. 1.108:** "Periodic Testing of Diesel Generators Used as On-Site Power Systems at Nuclear Power Plants."
- **R.G. 1.118:** "Periodic Testing of Electric Power and Protection Systems."

B.1.2 Industry Codes and Standards:

- **IEEE Std 446-1987,** "IEEE Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Application." - Presents generally recommended engineering principles, practices, and guidelines for the selection and application of emergency and standby power systems. This standard provides a comprehensive source of basic information.
- **IEEE Std 387-1984,** "IEEE Standard Criteria for Diesel Generator Units Applied as Standby Power Supplies for Nuclear Power Generating Stations" (Revision of ANSI/IEEE Std 387-1977). - Delineates principal design criteria and qualification testing requirements that, if followed, will help ensure that EDGs will meet performance and reliability requirements. This standard has been endorsed by the NRC in Rev. 3 of Reg Guide 1.9. It should be noted that this standard references other standards which contain valuable information.
- **IEEE Std 115-1983,** "Test Procedures for Synchronous Machines."
- **IEEE Std 308-1974,** "Standard Criteria for Class 1E Power Systems for Nuclear Power Generating Stations."
- **IEEE Std 749-1983,** "IEEE Standard Periodic Testing of Diesel-Generator Units Applied as Standby Power Supplies in Nuclear Generating Stations." Provides test criteria and requirements to periodically verify EDG availability and performance
- **ASME OM-S/G-1990,** "Standards and Guides for Operation and Maintenance of Nuclear Power Plants;" Part 16: "Inservice Testing and Maintenance of Diesel Drives in Nuclear Power Plants." Presents inservice testing and maintenance requirements of the diesel engine drives; includes sample test procedures, data sheets and examples of data trending.
- **ANSI/NEMA MG-1-1978,** "Motors and Generators."

- **ANSI/NFPA 37-1979, "Stationary Combustion Engines and Gas Turbines."**
- **ANSI/NFPA 70-1990, "National Electrical Code."**
- **ANSI/NFPA 70B-1987, "Recommended Practice for Electrical Equipment Maintenance."** Presents comprehensive basic information related to the function, requirements and economic considerations of an effective preventive maintenance program for industrial electric equipment
- **ANSI/NFPA 110-1985, "Standard for Emergency and Standby Power Systems."**
- **IEEE Std 650-1979, "IEEE Standard for Qualification of Class 1E Static Battery Chargers and Inverters for Nuclear Generating Stations."**

B.2 DOE Requirements for Testing and Maintenance of Emergency Power Systems

DOE Order 6430.1A, "General Design Criteria," dated April 6, 1989, provides general design criteria (GDC) for use in the acquisition of DOE facilities and to establish responsibilities and authorities for the development and maintenance of the criteria. Each of the 16 separate sections of the Order is devoted to a major building system or design specialty. Systems Section 16, "Electrical," contains the general requirements for electrical systems at DOE facilities. The GDC specifically related to Standby and Emergency Power Systems are contained in Sub-Section 1660, "Special Systems".

B.2.1 General Design Criteria for Emergency Power Systems at DOE Facilities

Section 1660-2 of DOE Order 6430.1A requires emergency power systems to comply with the following NFPA codes: NFPA-37, "Stationary Combustion Engines and Gas Turbines," NFPA-70, "National Electrical Code," NFPA-101, "Life Safety Code," and NFPA 110, "Emergency and Standby Power Systems." It should be noted that NFPA codes contain provisions considered necessary for safety. From a maintenance perspective, therefore, while compliance with NFPA codes will result in an installation that is essentially free from electrical hazards, it will not necessarily assure that the system is efficient, convenient, or adequate for good service or future expansion of electrical use. However, Section 1660-2 of the DOE Order also requires emergency power systems to comply with IEEE 446, "IEEE Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications," which provides a comprehensive source of engineering principals, practices and guidelines for the selection and application of emergency power systems. With regard to emergency power system capacity, Section 1160-2 of the Order requires such systems to be capable of maintaining full operation of emergency loads for the full time period specified by the DOE authority (minimum of 24 hours). Additionally, this section of the Order requires built-in features to facilitate operational testing on a periodic basis to verify readiness.

The GDC related to UPS systems are contained in Sub-Section 1660-3. This section of the Order requires the use of UPSs for all loads requiring guaranteed continuous power and stipulates compliance with IEEE-446.

B.2.2 Specific Requirements of Standards Referenced in the GDC

B.2.2.1 NFPA 70, Article 700-4 - Emergency Systems - Test and Maintenance:

- A test of the complete system upon installation and periodically thereafter shall be performed and witnessed by the authority having jurisdiction.
- Systems shall be tested periodically on a schedule acceptable to the authority having jurisdiction.
- Battery systems shall receive periodic maintenance.
- A written record shall be kept of all tests and maintenance.
- Means for testing all emergency lighting and power systems during maximum anticipated load conditions shall be provided.

B.2.2.2 NFPA 70, Article 700-5 - Emergency Systems - Capacity:

- Systems must have adequate capacity and rating to permit operation of all loads simultaneously. Emergency Power Systems are required to be capable of restarting emergency loads, such as motors, that may have stopped.

B.2.2.3 IEEE Std 446-1987, IEEE Recommended Practice for Emergency and Standby Power Systems, Chapter 8, Maintenance.

- Presents a consolidation of general PM recommendations for each major component of the system. This chapter defines PM for electrical equipment as a system of planned inspections, testing, cleaning, drying, monitoring, adjusting, corrective modification, and minor repair to maintain equipment in optimum operating condition and with maximum reliability.
- With regard to PM for internal combustion engines, IEEE-446 specifies the implementation of PM recommendations found in the equipment manufacturers Service Manual. Additionally, this section of the Standard emphasizes the need for adequate lubrication ("lubrication determines engine useful life more than any other factor") and identifies cleanliness as "the foundation of any PM program" since "dirt is a major cause of equipment failure".

Typical PM activities described in the Standard include:

- **Internal Combustion Engines:** The schedule of PM tasks given in Table B-1 is described in the IEEE Std-446 as a "typical" service guide for a 1800 rev/min EDG:
- **Generators:** Accumulation of a 30 mil layer of dust can raise the operating temperature of a generator winding ten degrees

Centigrade. To address this concern, IEEE-446 recognizes equipment cleanliness to be of primary importance with emphasis placed on cleanliness of ventilation ducts and windings. Regularly scheduled inspections should verify tightness of all connections, insulation integrity, and condition of all bearings and brushes.

- **UPS:** The PM consists of cleaning and inspecting at regular periodic intervals. All parts should be inspected for evidence of overheating and physical damage. All terminals should be tightened, their integrity verified, and the condition of the battery should be checked. Following scheduled PM activities, voltage and frequency output should be checked and adjusted as necessary and the system checked for proper operation by simulation of a power failure.
- **Batteries:** The IEEE-446 identifies cleanliness, electrolyte level, voltage, and specific gravity records combined with visual inspections as forming the basis of a PM program for batteries and describes the following "typical" maintenance schedule:

Daily: Check bus voltage, pilot cell hydrometer and charge/discharge current.

Monthly: Check cell electrolyte level, filler cap vent holes (plugged) and inspect electrode plates for color, particles, damage and swelling.

Quarterly: Perform equalizing charge. After completion, take hydrometer readings of all cells, clean cell tops with soda solution, and check condition/torque of cell terminals/straps.

Table B-1

Internal Combustion Engines - Schedule of PM Tasks

<p>(1) Every 25 Hours / 4 Months:</p> <ul style="list-style-type: none">- Adjust fan and alternator belt- Add oil to cup for distributor housing- Change oil in oil type air filter <p>(2) Every 50 Hours / 6 Months:</p> <ul style="list-style-type: none">- Perform 25 hour service- Drain/refill crankcase- Clean crankcase ventilation air filter- Clean dry-type air filters- Check Transmission oil- Check Battery- Clean external engine surface <p>(3) Every 100 Hours / 8 Months:</p> <ul style="list-style-type: none">- Perform 25 and 50 Hour service- Replace oil filter- Check crankcase ventilator valve- Clean crankcase inlet air cleaner- Clean fuel filter- Replace dry-type air cleaner	<p>(4) Every 200 Hours / 12 Months:</p> <ul style="list-style-type: none">- Perform 25, 50, and 100 hour service- Adjust distributor contact points- Check spark plugs (gap/fouling)- Check timing <p>(5) Every 500 Hours / 24 Months:</p> <ul style="list-style-type: none">- Perform 25, 50, 100 and 200 hour service- Drain/refill transmission- Replace crankcase ventilator valve- Replace one-piece type fuel filter- Check valve tappet clearance- Check crankcase vacuum- Check compression- Check carburetor adjustments
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SUMMARY OF INDUSTRY/REGULATORY STANDARDS AND GUIDANCE

GENERATORS:

STANDARD/GUIDANCE

NFPA Standard 110-1985, "Standard for Emergency and Standby Power Systems."

KEY ELEMENTS

1. PM program based on manufacturer's recommendations.
2. Maintain manufacturer's instruction manuals for all major components.
3. Availability of tools and testing devices.
4. Availability/Control of replacement parts.
5. Equipment maintained to provide reasonable assurance that the system will be capable of supplying service within the time specified and continue to operate for the duration required.
6. Routine maintenance and operational testing performed in accordance with a written schedule.
7. Documented record of all inspections, tests, and repairs.
8. Transfer switches should be included in maintenance program.
- 9.* Inspected weekly and exercised under load conditions at intervals of not more than 30 days.
- 10.* Exercise systems under operating temperature conditions at not less than 50 percent of total connected load (not less than 30 percent and preferably 50 percent of nameplate rating) at least once monthly for a minimum of 30 minutes. More stringent conditions should be considered as recommended by the manufacturer.
11. Equivalent loads used for testing shall be automatically replaced with emergency loads in case of failure of primary source.
12. Load Tests include starts from standby conditions.
13. Transfer switch should be electrically operated from normal to alternate position and return during monthly test.
- 14.* Annually exercise main and feed circuit breakers (CBs) between power source and transfer switch load terminals. Medium and high voltage CBs exercised at 6 month intervals and tested under simulated overload conditions every two years.
15. PM program overseen by properly instructed individual.

* For Level 1 Equipment as defined in the Standard.

SUMMARY OF INDUSTRY/REGULATORY STANDARDS AND GUIDANCE

GENERATORS:

STANDARD/GUIDANCE

IEEE Standard 387-1984, "IEEE Standard Criteria for Diesel Generator Units Applied as Standby Power Supplies for Nuclear Power Generating Stations." This Standard delineates principal design criteria and qualification testing requirements.

KEY ELEMENTS

1. All testing performed in accordance with a written test plan.
2. Test documentation to include:
 - a) Equipment performance specifications,
 - b) Specific feature(s) to be demonstrated by the test,
 - c) Test plan, and
 - d) Report of test results.
3. PM program established for engine, generator and all supporting systems based on manufacturer recommendations.
4. PM procedures should include specific programs for major portions of the EDG unit (i.e., engine, generator, support systems).
5. Maintenance of records to provide basis for an analysis of the unit's overall performance. Records include, as a minimum:
 - a) All start attempts; maintenance, repair, and out-of-service time histories; cumulative maintenance and operating data; cumulative statistical analysis of EDG test results, together with results of operation of the EDG when required by actual demand, and
 - b) Critical failure mechanisms, human errors, and common mode failures, including cause(s) and corrective actions.

SUMMARY OF INDUSTRY/REGULATORY STANDARDS AND GUIDANCE

GENERATORS:

STANDARD/GUIDANCE

Regulatory Guide 1.9 Rev. 3, "Selection, Design, Qualification, and Testing of Emergency Diesel Generator Units Used as Class 1E Onsite Electric Power Systems at Nuclear Power Plants."

KEY ELEMENTS

I. Surveillance Testing:

Periodic testing to demonstrate continued capability and reliability of the EDG to perform its intended function.

NOTE: Details of specific tests identified below are described in Regulatory Position 2.2 of the Regulatory Guide (RG).

a) Monthly Testing:

Start and load run test each EDG at least once in 31 days (maximum allowable extension not to exceed 25 percent of surveillance interval). To minimize stress and wear, EDG may be brought to rated speed and voltage in time recommended by manufacturer.

b) Six Month Testing (184 Days):

Demonstrate capability to start from the standby condition and provide power. Fast start EDG from standby condition to verify that EDG reaches required voltage and frequency within acceptable limits and time as specified in plant technical specifications. Following this test the EDG should be loaded.

c) Refueling Outage (18-24 Months):

Demonstrate EDG design capability:

- Fast start,
- Auto start signal tests,
- Single load rejection,
- Full load rejection,
- Endurance and margin test,
- Hot restart,
- Synchronizing test,
- Protective-trip bypass,
- Test mode changeover test, and
- Redundant unit test.

II. Reliability Goals and Monitoring:

Minimum reliability targeted at 0.95 or 0.975 per demand (depending on plant specific Station Blackout coping duration, see RG 1.155):

- EDG reliability monitored by monthly testing,
- All data from planned and unplanned demands is used, and
- Cumulative maintenance outage times (impact on EDG availability) are considered.

NOTE: See RG for calculational method to determine point estimate reliability from last 20, 50, and 100 start and load run demands.

III. Record Keeping:

Section 7.5.2, "Records and Analysis," of IEEE Standard 387-1984 should be supplemented as follows: Licensees should retain in an auditable and retrievable form the information related to EDG failures for start and load-runs that occur during all planned and unplanned demands and underlying failure causes and corrective actions taken in response to individual EDG failures.

SUMMARY OF INDUSTRY/REGULATORY STANDARDS AND GUIDANCE

GENERATORS:

STANDARD/GUIDANCE

ASME OM-S/G-1990, "Standards and Guides for Operation and Maintenance of Nuclear Power Plants," Part 16, "Inservice Testing and Maintenance of Diesel Drives in Nuclear Power Plants."

KEY ELEMENTS

I. Preoperational and Post Major Maintenance Testing:

Perform initial check of engines systems, subsystems, and support systems to ensure overall unit will operate as designed. Checks include flushes, hydrostatic tests, visual inspections, functional tests of support components and subsystems, and any additional tests recommended by the manufacturer.

II. Baseline Testing:

Data is collected during initial system operation and following major engine overhaul at specific operating conditions to establish a basis for comparison with subsequent operating conditions or parameters. Baseline testing consists of:

- a) Prestart checks,
- b) Low speed run,
- c) Rated Speed Run (apply 25 -50 percent of continuous load for 15 minutes), and
- d) Data requirements at rated speed:
 - 75 percent continuous load for two hours (minimum), then
 - 100 percent load for 2 hours (minimum), then
 - 110 percent load for $\frac{1}{2}$ hour (minimum)

Record system operating parameters under each load condition (see ASME OM/16 for details).

III. Inservice Testing:

1. Daily Visual Inspections.
2. Weekly Inspections - Perform daily inspections, check fluid levels, remove trapped moisture from air start tanks.
3. Monthly Inspections:
 - Perform weekly inspections,
 - Fuel and lube oil samples,
 - Manual slow start, gradual application of load (75% -100% continuous rated load),
 - Operate for minimum of one hour; log data at 30 minute intervals, and
 - Cooldown - reduce load, run for 5 minutes.
4. Quarterly Inspections:
 - Perform monthly inspections,
 - Visually inspect and service auxiliaries,
 - Lube oil and jacket water sample analysis,
 - Check and lubricate fuel control linkage, and
 - Check governor and turbocharger oil level.

(continued)

SUMMARY OF INDUSTRY/REGULATORY STANDARDS AND GUIDANCE

GENERATORS:

STANDARD/GUIDANCE

(continued)

ASME OM-S/G-1990, Standards and Guides for Operation and Maintenance of Nuclear Power Plants, Part 16, "Inservice Testing and Maintenance of Diesel Drives in Nuclear Power Plants"

KEY ELEMENTS

(continued)

5. Refueling Outage (18-24 months):

- Check safety/shutdown devices,
- Injection nozzle inspection and test,
- Fuel oil sample analysis,
- Fuel injection timing,
- Inspect all gears, intake/exhaust ports, piston rings, and liners,
- Hydrostatic test/inspect engine cooling system,
- Check crankshaft end float and bearings, torsional dampers,
- Inspect cam shaft, roller faces, timing chains, engine blower and/or turbo, and engine component drive couplings,
- Perform governor maintenance,
- Check engine/generator alignment,
- Replace filters,
- Inspect lube oil, jacket water and turbo heat exchanger tubes, and
- Perform quarterly tests.

IV. Engine Operating Data & Records:

1. Baseline and Inservice Data:

- Example given in OM/16 (Appendices C and D) - consult manufacturer to determine critical operating parameters for specific machine.

2. Data Evaluation and Trending:

- Review and trend engine performance parameters against manufacturer's accepted values
- Data plotted at frequent intervals to reveal trends
- Examples given in OM/16 (Appendix E)

3. Root Cause:

- Accurate assessment of what caused engine to fail so that proper corrective actions can be taken.

SUMMARY OF INDUSTRY/REGULATORY STANDARDS AND GUIDANCE

GENERATORS:

STANDARD/GUIDANCE

NRC Reg Guide 1.108 Rev. 3, "Periodic Testing of Diesel Generator Units Used as Onsite Electric Power Systems at Nuclear Power Plants." Provides design and operational provisions for periodic testing of EDGs.

KEY ELEMENTS

I. General:

1. EDG designed to accommodate testing.
2. EDG designed to be testable during plant operation and shutdown:
 - Capability to test each EDG independently of redundant units,
 - Testability considered in selection/location of instrument sensors and critical components,
 - Periodic testing should not impair capability of unit to function on receipt of actual demand signal,
 - Control Room indication of EDG status (i.e. under test, ready standby, lockout),
 - Surveillance system capable of indicating which protective trip is actuated first, and
 - All EDG protective trips in force during testing.
3. Detailed, step-by-step procedures provided for each test.
4. Root Cause determined subsequent to any failure.

II. Testing:

1. Preoperational and Refueling Outages (18 months); Demonstrate:
 - Start on simulated loss of offsite power,
 - Proper operation of design accident loading sequence to design load requirements (voltage and frequency maintained within acceptable limits),
 - Ability to carry full load for not less than 24 hours (22 hours at continuous rating plus 2 hours at 2-hour load rating of EDG),
 - Proper operation during load shedding (largest single load, and complete loss of load),
 - Functional capability at full-load temperature,
 - Synchronization capability,
 - Engine operability during transfer of fuel supplies (if required),
 - EDG capability not impaired during periodic testing, and
 - Demonstrate required reliability.
2. Periodic Testing
 - Proper start: required voltage/frequency attained within acceptable limits and time, verify components required for automatic start are operable,
 - Full-load capability (continuous rated full load) for not less than 1 hour,
 - Test interval varies based on previous reliability performance^{**}:
 - 1 or 0 failures in last 100 valid tests = 31 days
 - 2 failures in last 100 valid tests = 14 days
 - 3 failures in last 100 valid tests = 7 days
 - 4 or more failures in last 100 = 3 day interval.

* Valid tests and failures are defined in the Reg Guide.
** Accelerated testing is no longer endorsed by NRC.

III. Records and Reports:

1. Log all start attempts, maintenance, repairs, out-of-service time, and operating data,
2. Trend critical failure mechanisms, human errors, and common mode failures, and
3. Report all failures.

SUMMARY OF INDUSTRY/REGULATORY STANDARDS AND GUIDANCE

GENERATORS:

STANDARD/GUIDANCE

IEEE Standard 749-1983, "IEEE Standard Periodic Testing of EDG Units Applied as Standby Power Supplies in Nuclear Power Stations."

The purpose of this standard is to provide test criteria and requirements which result in periodic demonstration of availability and performance for EDG units after completion of preoperational testing.

Periodic Tests included in scope:

- Availability tests,
- System operational tests,
- Independence verification tests.

KEY ELEMENTS

I. General Requirements:

1. Overall EDG PM program to be established which includes, as a minimum:
 - Routine inspections of all fluid levels and pressures,
 - Routine inspections for proper alignment of EDG auxiliary and support systems,
 - Routine program to maintain auxiliary and support systems (in accordance with manufacturers recommendations),
 - Routine calibration of sensors, instruments, timers, and relays,
 - Routine fuel sample analysis.
2. Test equipment shall not cause a loss of independence between redundant EDGs.
3. Periodic testing shall not impair ability of unit to function in response to valid accident signals.
4. All EDG protection circuits and alarms to be operable during testing.
5. Detailed written test procedures which include all manufacturer's applicable pretest recommendations.
6. Test procedures that involve starting/stopping of EDG shall include the following:
 - Record of all prestart data (lube oil pressure, temperature, and level; jacket water temperature, etc.),
 - Record of elapsed time from start signal to nominal speed,
 - Confirmation of generator voltage and frequency within prescribed limits,
 - Record of all operating parameters (pressure, temperature, electrical, level) at the following times:
 - Beginning of any load test,
 - 1 hour intervals, and
 - At end of any load test.

(continued)

SUMMARY OF INDUSTRY/REGULATORY STANDARDS AND GUIDANCE

GENERATORS:

STANDARD/GUIDANCE

(continued)

IEEE Standard 749-1983, "IEEE Standard Periodic Testing of EDG Units Applied as Standby Power Supplies in Nuclear Power Stations."

KEY ELEMENTS

(continued)

II. Specific Requirements:

Periodic testing consists of availability, systems operation, and independence verification tests:

- A. **Availability Tests:** Demonstrate proper start and load acceptance capability at intervals of 31 days (or less depending on demonstrated performance of EDG unit) by:
 - EDG start, verify proper voltage and frequency are attained automatically, and
 - 1 hour full load operation.
- B. **System Operational Tests:** Demonstrate ability of EDG to perform its intended function under simulated accident and loss of offsite power (LOOP) conditions at intervals of 18 months or less as follows:
 - 1. **Integrated System Test:** Demonstrate proper operations during LOOP and accident signal. Verify:
 - Emergency buses are de-energized and shed load,
 - Automatic EDG start, acceptable voltage/frequency,
 - Load sequence.
 - a) Simulate accident signal then LOOP,
 - b) Simulate LOOP then accident signal.Alternate (a) and (b) during successive test periods.
 - 2. **Full Load Test:** Demonstrate ability to carry full (continuous rated) load for at least 8 hours.
 - 3. **Safety Load Rejection Test:** Demonstrate proper operation during loss of largest single load.
 - 4. **Full Load Rejection Test:** Demonstrate proper operation during a complete loss of the continuous rated load.
 - 5. **Synchronizing Test:** Demonstrate ability to synchronize EDG with off-site power while unit is connected to an emergency load and transfer this load to off-site power system.
 - 6. **Fuel Supply Transfer Test:** Demonstrate EDG will perform properly when switching from one fuel supply to another (if a design requirement).
 - 7. **Isolation Test:** Demonstrate capability to supply emergency power within required time is not impaired during availability test. Alternate the following tests during successive test periods:
 - (a) During Availability Test, simulate accident signal; verify EDG isolates from off-site power source, remains running, and accident loads are properly energized from the off-site power source
 - (b) During Availability Test, simulate LOOP; verify emergency bus isolates from off-site power, EDG energizes Emergency bus, and accident loads sequence on.
 - 8. **Protective Trip Test:** Demonstrate EDG protective trips are bypassed during LOOP plus concurrent accident signal.
- C. **Independence Verification Test:** Verify redundant units auto-start and load simultaneously, check for Common Failure Mode (perform every 10 years or subsequent to any modification having potential to affect EDG independence).

CROSS INDEX OF KEY INDUSTRY/REGULATORY PM PROGRAM CRITERIA

EMERGENCY DIESEL GENERATORS

	NFPA-110	IEEE-387	RG 1.9 Rev. 3	ASME OM-16	RG 1.108	IEEE-749
PM Program Based on Manufacturers' Recommendations	■	■		■		■
Documented Plan, Procedures, Schedule, and Data	■	■	■	■	■	■
Daily Inspection Criteria				■		
Weekly Inspection Criteria	■			■		
Monthly Inspection & Test Criteria	■		■	■	■	■
Major Testing (Refueling Outage)			■	■	■	■
Trending of Data		■	■	■	■	
Reliability Monitoring Program		■	■		■	
Root Cause Analysis		■	■	■	■	

SUMMARY OF INDUSTRY/REGULATORY STANDARDS AND GUIDANCE

UNINTERRUPTIBLE POWER SUPPLIES and BATTERIES

STANDARD/GUIDANCE

NFPA Standard 110A, "Stored Electrical Energy Emergency and Standby Power Systems," 1989 Edition.

Chapter 6 of this standard addresses routine maintenance and operational testing requirements for Stored Emergency Power Supply Systems (i.e. stored electrical energy systems providing an alternate source of electrical power in the event the normal source of electrical power fails). This standard is typically used in conjunction with other standards and guidance.

Equipment covered:

- Batteries
- Uninterruptible Power Supplies
- Automatic Transfer Switches.

Appendix A of this standard contains a suggested maintenance schedule which identifies the procedure and frequency of maintenance for the above equipment.

KEY ELEMENTS

General Requirements:

1. Established program of routine maintenance and operational testing based on manufacturers' recommendations.
2. Maintain instruction manuals, special tools and spare parts.
3. Maintenance and Operational Testing:
 - a) Equipment maintained to provide reasonable assurance that system will be capable of performing intended function when required,
 - b) Written record of all inspections, tests, and repairs.
4. Operational Inspection and Testing:
 - a) Monthly inspection, including:
 - Visual inspections of battery and charger,
 - Check battery electrolyte level,
 - Clean/Regrease terminals,
 - Check/Record Specific Gravity of pilot cells,
 - Load test battery; record output volts and battery volts at beginning and end of test. Record duration of test,
 - Check indicator lamps, meters, controls, and
 - Check that load value is within equipment rating.
 - b) Yearly full load test,
 - c) Testing/maintenance performed by trained personnel, and
 - d) Exercised quarterly under connected load.

SUMMARY OF INDUSTRY/REGULATORY STANDARDS AND GUIDANCE

BATTERIES

STANDARD/GUIDANCE

IEEE Standard 450-1987, "IEEE Recommended Practice for Maintenance, Testing, and Replacement of Large Lead Storage Batteries for Generating Stations and Substations."

Provides recommended practices of maintenance, test schedules, and test procedures to optimize performance of large lead acid storage batteries.

KEY ELEMENTS

I. Maintenance

A. Safety:

1. Personnel Training: Work performed by knowledgeable personnel using proper tools and protective equipment.
2. Methods: Work methods preclude circuit interruption or arcing in vicinity of battery.
3. Protective Equipment:
 - Goggles and Face Shields
 - Acid-resistant Gloves
 - Protective Aprons
 - Portable or Stationary water facilities for rinsing eyes/skin
 - Bicarbonate of soda (mixed 1 pound to 1 gallon of water)
4. Precautions.

B. Inspections: All inspections made under normal float voltage conditions; document all data.

1. Monthly General Inspection - Check and record:
 - Float voltage at battery terminal,
 - Appearance/Cleanliness,
 - Charger output current & voltage,
 - Electrolyte levels,
 - Cracked cells/leakage of electrolyte,
 - Corrosion at terminals, connectors, or racks,
 - Ambient temperature/ventilation equipment condition, and
 - Pilot cell (if used) voltage, specific gravity, and electrolyte temperature.
2. Quarterly Inspection: Augment General Inspection by checking and recording:
 - Specific gravity of each cell,
 - Cell voltage and total battery terminal voltage,
 - Representative cell temperature.
3. Yearly Inspection: Augment Quarterly Inspection by checking and recording:
 - Detailed visual inspection of cell condition,
 - Cell-to-cell and terminal connection resistance,
 - Battery rack integrity.
4. Special Inspections:
 - Performed in event of abnormal condition; for example: severe discharge or overcharge,
 - Perform Monthly and Quarterly inspection tasks.

(continued)

SUMMARY OF INDUSTRY/REGULATORY STANDARDS AND GUIDANCE

BATTERIES

STANDARD/GUIDANCE

(continued)

IEEE Standard 450-1987, "IEEE Recommended Practice for Maintenance, Testing, and Replacement of Large Lead Storage Batteries for Generating Stations and Substations."

KEY ELEMENTS

(continued)

- C. Corrective Actions - Standard provides detailed guidance for identifying and correcting adverse/abnormal battery conditions.

II. Capacity Test Schedule

Capacity tests determine:

- If battery meets specification or manufacturer's rating,
- If "as found" performance is within acceptable limits, and
- If "as found" condition meets design requirements.

A. Acceptance Test:

- Upon installation or at factory.

B. Performance Test:

- Within first 2 years of service,
- At 5 year intervals,
- Annually for battery showing signs of degradation (battery capacity drops more than 10% of rated capacity from its capacity on previous performance test) or, battery has reached 85% of its rated service life.

C. Service Test:

- Test of battery capability - "as found" ability to satisfy design requirements (battery duty cycle) of DC system; may be required to verify performance upon completion of installation,
- Performed for Class 1E batteries at commercial Nuclear Power Plants as part of preoperational and periodic DC system tests.

D. Procedure for Battery Capacity Tests:

Standard provides detailed guidance for performing battery capacity tests. Specific topics addressed include:

- Initial conditions,
- Test duration,
- Test discharge rate,
- Acceptance and Performance Tests,
- Determination of battery capacity, and
- Restoration to normal service.

E. Battery Replacement Criteria:

F. Records:

SUMMARY OF INDUSTRY/REGULATORY STANDARDS AND GUIDANCE

BATTERIES

STANDARD/GUIDANCE

IEEE Standard 484-1987, "IEEE Recommended Practice for Installation Design and Installation of Large Lead Storage Batteries for Generating Stations and Substations."

Provides recommended design practices and procedures for storage, location, mounting, ventilation, instrumentation, preassembly, assembly, and charging of large lead storage batteries.

KEY ELEMENTS

I. Safety:

1. Protective Equipment.
2. Procedures.

II. Installation Design Criteria:

1. Location.
2. Mounting.
3. Instrumentation/Alarms - Battery only.

III. Nuclear Power Plant Class 1E Batteries:

1. Additional design criteria (Location and Mounting) applicable to batteries used in Class 1E systems at Nuclear Power Plants.

IV. Installation Procedures:

1. Receiving/Storage.
2. Unpacking.
3. Assembly (Rack Assembly/Cell Mounting and Connections).
4. Freshening Charge and Testing.

V. Records:

SUMMARY OF INDUSTRY/REGULATORY STANDARDS AND GUIDANCE

BATTERIES

STANDARD/GUIDANCE

IEEE Standard 485-1983, "IEEE Recommended Practice for Sizing Large Lead Storage Batteries for Generating Stations and Substations."

Describes methods for defining the DC load and sizing battery to supply that load.

KEY ELEMENTS

I. Defining Loads:

1. General Considerations:

- a) Conditions which require battery to supply load:
 - DC system load exceeds max output of battery charger,
 - Output of battery charger interrupted, and
 - Auxiliary AC power is lost.
- b) Most severe condition used to determine battery size,
- c) Plot of battery duty cycle (amps/time for each load) under most severe condition.

2. Load Classifications:

- a) Continuous Loads:
 - Energized throughout duty cycle.
- b) Noncontinuous Loads:
 - Energized during a portion of the duty cycle,
 - May come on at any time within duty cycle,
 - May be on for a set length of time; be removed automatically or by operator action; or continue to end of duty cycle.
- c) Momentary Loads:
 - Short duration: less than one minute,
 - Can occur repeatedly.

3. Duty Cycle Diagram Preparation:

4. Cell Selection:

- Discusses factors, other than capacity, that should be considered in selecting a cell design for a particular application.

5. Determining Battery Size:

- Three basic factors govern size: (1) maximum system voltage, (2) minimum system voltage, and (3) duty cycle. The Standard provides detailed guidance for determining proper battery size.

SUMMARY OF INDUSTRY/REGULATORY STANDARDS AND GUIDANCE

UNINTERRUPTIBLE POWER SUPPLIES

STANDARD/GUIDANCE

IEEE Standard 944-1986, "IEEE Recommended Practice for Application and Testing of Uninterruptible Power Supplies for Power Generating Stations."

Defines application and performance requirements for low-voltage UPS systems. Addresses requirements for solid state UPSs only. Application requirements for batteries and battery chargers not included,

KEY ELEMENTS

I. Service Conditions:

1. Usual Service Conditions and Normal Ranges.
2. Unusual Service Conditions.

II. Design Application Requirements:

1. UPS Application.
2. Performance Requirements.
3. Type/Size Selection Considerations.
4. Special Considerations.
 - System Reaction,
 - Availability.
5. UPS Power Source Requirements.
6. Output Requirements:

UPS should meet the output requirements for any load from 0% to 100% of UPS rating. Specific design criteria discussed in the Standard:

 - Capacity,
 - Voltage,
 - Frequency,
 - Grounded Enclosure and Neutral,
 - Output Voltage Waveform,
 - Transients,
 - Short Circuits,
 - Operating and Interrupting Time,
 - Overload Rating,
 - Synchronizing,
 - Audible Noise, and
 - Radiated and Conducted Electromagnetic Emission.
7. Controls, Instruments and Alarms.
8. Procurement Document Requirements.
9. Testing Requirements: Factory performed tests prior to shipment. These tests are typically followed by supplemental tests upon arrival of the UPS at the site.

SUMMARY OF INDUSTRY/REGULATORY STANDARDS AND GUIDANCE

UNINTERRUPTIBLE POWER SUPPLIES

STANDARD/GUIDANCE

IEEE Standard 650-1979, "IEEE Standard for Qualification of Class 1E Static Battery Chargers and Inverters for Nuclear Power Generating Stations."

Describes methods for qualifying battery chargers and inverters for Class 1E installations in mild environments. This Standard does not specify performance requirements or address maintenance and periodic testing. However, it does provide insight on factors to be considered in the development of a PM program for UPS equipment. A specific example is the determination of maintenance replacement intervals of limited life components such as, electrolytic capacitors.

KEY ELEMENTS

- I. Maintenance factors (including component aging) which should be considered in UPS PM program.

SUMMARY OF INDUSTRY/REGULATORY STANDARDS AND GUIDANCE

BATTERIES/BATTERY CHARGERS/DC DISTRIBUTION EQUIPMENT

STANDARD/GUIDANCE

IEEE Standard 946-1985, "IEEE Recommended Practice for the Design of Safety-Related DC Auxiliary Power Systems for Nuclear Power Generating Stations."

Provides design guidance for safety-related DC auxiliary power systems at Nuclear Power Stations.

KEY ELEMENTS

I. General:

1. Description and Operation.
2. Number of Batteries.
3. Number of Chargers and Distribution Panels.
4. System Voltage Considerations.
5. Physical Layout of Redundant Equipment.

II. Battery Design/Maintenance:

1. Determination of Duty Cycle and Size (Capacity); References IEEE Standard 485.
2. Installation Design; References IEEE Standard 484.
3. Maintenance, Testing, Replacement; References IEEE Standard 450.
4. Environmental/Seismic Qualification; References IEEE Standard 535.

III. Battery Chargers:

1. General Description.
2. Determination of Required Rating.

IV. Distribution System And Equipment:

1. Description and Rating.
2. Typical Diagram of an Acceptable System.
3. Voltage Ratings for DC Powered Components.
4. Instrumentation, Controls and Alarms.
5. Special DC Loads: Load Transfers, Current Demand Increase as Voltage Decreases, Switching Surges.
6. Design Features to Assist Battery Testing.
7. Cross-Tie Between Buses.
8. Qualification.
9. Available Short Circuit Current.

V. Spare Equipment:

1. Need for spare equipment based on systems design features and operating restrictions.

SUMMARY OF INDUSTRY/REGULATORY STANDARDS AND GUIDANCE

Ni-Cad BATTERIES

STANDARD/GUIDANCE

IEEE Standard 1106-1987, "IEEE Recommended Practice for Maintenance, Testing, and Replacement of Nickel-Cadmium Storage Batteries for Generating Stations and Substations."

Provides maintenance, test schedules and testing procedures for optimizing the life and performance of nickel-cadmium batteries designed for continuous float applications.

I. Maintenance:

1. Safety:

- Safe Work Methods,
- Protective Equipment, and
- Precautions.

2. Inspections:

a) Monthly (less than 31 Days) Record:

- Float voltage at battery terminals,
- Appearance/Cleanliness,
- Charger output current and voltage,
- Electrolyte levels,
- Cracks in cells/electrolyte leakage,
- Corrosion of terminals, connectors, or rack,
- Operability of ventilation equipment, and
- Pilot cell electrolyte temperature.

b) Quarterly:

- Augment Monthly inspection with recording of voltage of each cell.

c) Yearly:

- Augment Quarterly inspection by checking and recording cell-to-cell and terminal resistance.

d) Special Inspections; If the battery has experienced an abnormal condition (e.g. severe discharge or severe overcharge) perform Monthly and Quarterly Inspections.

3. Corrective Actions; Standard provides detailed guidance for identifying and correcting adverse/abnormal battery conditions.

II. Capacity Test Schedule:

Capacity tests determine:

- If battery meets specification or manufacturers rating,
- If "as found" performance is within acceptable limits, and
- If "as found" condition meets design requirements.

1. Acceptance Test:

- Upon installation or at factory.

2. Performance Test:

- Within first 2 years of service,
- At 5 year intervals, and
- Annually upon battery showing signs of excess capacity loss (i.e., battery capacity drops more than 1.5 percent per year of rated capacity from its capacity on previous performance test).

(continued)

SUMMARY OF INDUSTRY/REGULATORY STANDARDS AND GUIDANCE

Ni-Cad BATTERIES

STANDARD/GUIDANCE

(continued)

IEEE Standard 1106-1987, "IEEE Recommended Practice for Maintenance, Testing, and Replacement of Nickel-Cadmium Storage Batteries for Generating Stations and Substations."

KEY ELEMENTS

(continued)

3. Service Test:

- Test of battery capability - tests "as found" ability to satisfy design requirements (battery duty cycle) of DC system - may be required to meet verify performance upon completion of installation,
- Performed for Class 1E batteries at commercial nuclear power plants as part of preoperational and periodic DC system tests.

4. Procedure for Battery Capacity Tests: Standard provides detailed guidance for performing battery capacity tests. Specific topics addressed include:

- Initial conditions,
- Test duration,
- Test discharge rate,
- Acceptance and performance tests,
- Determining battery capacity,
- Service test, and
- Restoration to normal service.

5. Battery Replacement Criteria.

6. Records.

SUMMARY OF INDUSTRY/REGULATORY STANDARDS AND GUIDANCE

EMERGENCY POWER EQUIPMENT - GENERAL

STANDARD/GUIDANCE

IEEE Standard 446-1987, "IEEE Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications."

This is a general guidance document that provides basic engineering principals, practices, and guidelines, for selection and application of emergency and standby power system equipment. Provides description of equipment and system configurations. Chapter 8 of the Standard includes typical maintenance schedules for optimizing the life and performance of emergency power system equipment.

KEY ELEMENTS

I. Generator Systems:

1. Diesel and Gas Engine Driven Generators.

II. Stored Energy Systems:

1. Battery Systems.
2. Battery/Inverter Systems.
3. Motor Generators and Rotating UPS Systems.

III. Electrical Protection:

1. Short Circuit Considerations.
2. Transfer Devices.
3. Generator Protection.
4. Prime Mover Protection.
5. UPS Protection.

IV. Maintenance:

1. Internal Combustion Engines.
2. Gas Turbine.
3. Generators.
4. Static UPS.
5. Batteries.
6. Automatic Transfer Switch.

CROSS INDEX OF KEY INDUSTRY/REGULATORY PM PROGRAM CRITERIA

UNINTERRUPTIBLE POWER SUPPLIES

	NFPA-110A	IEEE-944	IEEE-446	IEEE-650
PM Program Based on Manufacturers' Recommendations	■		■	
Documented Plan, Procedures, Schedule, and Data	■			
Daily Inspection Criteria				
Weekly Inspection Criteria	■			
Monthly Inspection Criteria	■		■ ("Regular Intervals")	
Test Criteria	■ (Yearly load test)	■ (Design Test Criteria)		
Trending of Data				
Reliability Monitoring Program				
Root Cause Analysis				
Design/Application/Performance Requirements		■		
Replacement of "Limited Life" Components				■

CROSS INDEX OF KEY INDUSTRY/REGULATORY PM PROGRAM CRITERIA

BATTERIES

	NFPA-110	IEEE-450	IEEE-484	IEEE-485	IEEE-946	IEEE-1106 (Ni-Cad)
PM Program Based on Manufacturers' Recommendations	■	■				■
Documented Plan, Procedures, Schedule, and Data (Records)	■	■	■			■
Daily Inspection Criteria						
Weekly Inspection Criteria	■	■				
Monthly Inspection & Test Criteria	■	■				■
Major Testing		■				■
Trending of Data		■				■
Battery Replacement Criteria		■				■
Safety		■	■			■
Design Practices			■	■ (DC Load, Battery Sizing)	■ (Refers to IEEE 485 & IEEE 486)	
Root Cause Analysis		■				■

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