ONR207 - National and International Good Practices for Diesel Generators

Date:	5th April 2016
Client Reference:	ONR 207
Amec Foster Wheeler Reference:	203171-TR-201994
Issue Number:	01

Report for

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ONR 207

Our Reference

203171-TR-201994

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No.	Details	Date
01	Formal issue	5th April 2016

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1. Introduction

1. Amec Foster Wheeler has been tasked by ONR to carry out research to build up a body of knowledge that will enable ONR to produce enhanced guidance on national and international relevant good practice for essential diesel generators to assist with regulatory judgements and decision making.
2. Essential/Emergency Diesel Generators (EDGs) are critical safety components of Generation II & III Nuclear Power Plants because they provide crucial electrical power necessary to activate and control reactor cooling and safety systems in the event of a Loss of Off-site Power (LOOP) event, and to prevent critical Station Blackout (SBO) scenarios. The reliability of EDGs can therefore be one of the main factors affecting the risk of core damage from a station blackout event. Thus learning from international operational experience, incident and event reports relevant to EDGs within the nuclear sector and from wider high integrity industries and applications, can contribute greatly to reducing the risk of station blackout and core damage.
3. Generally a reactor unit will be equipped with 2-5 EDGs, ideally physically-separated, with isolated control systems and not relying on common interconnection. In some installations, multi-unit plants implement the capability to cross-connect EDGs between reactor units.
4. The composition of each EDG includes both principal and auxiliary components. The principal components are the diesel engine, generator (alternator) and control systems. These principal EDG components are typically classified in the highest safety category for plant equipment. The auxiliary components are sub-systems that are not directly-related to the operation of the EDG, such as ventilation and draining equipment. The content of the report therefore primarily encompasses operational practices and learning for the principle components and systems together with details and references of important supporting auxiliary components.

1.1 Terminology

5. From investigations into similar high-integrity applications and industries which are reliant upon diesel generators, various terminologies are used to describe and refer to the generators, including:
   - Emergency Generators (EGs)
   - Emergency Diesel Generators (EDGs)
   - Standby Generators
   - High-Integrity Diesel Generators
   - Back-Up Generators and
   - Essential Diesel Generators
6. Within industry, exact definitions or delineations between these terminologies are limited or do not exist, therefore the terms are used interchangeably within this report.
7. Diesel generators are operated in different modes according to operational requirements, as per below classifications:
   - 'Continuous'
   - 'Prime'
   - 'Standby' - as applicable to the Nuclear Industry

1.2 Abbreviations

DG	Diesel Generator
E,C&I	Electrical, Control & Instrumentation
EDG	Emergency Diesel Generator

LOOP	Loss of Off-site Power
PMG	Permanent Magnet Generators
PWM	Pulse Width Modulation
SBO	Station Blackout
THD	Total Harmonic Distortion
UPS	Uninterruptable Power Supply
VAR	Volts Amperes, Reactive

1.3 Comparable High Integrity Applications and Industries

8. Identified high integrity industries with comparable reliance and dependency on diesel generators include:

- Conventional power stations (emergency site/house loads, black start)
- Hospitals
- Data Centres (Server Farms/IT centres)
- Airports
- Utility power distribution monitoring and control centres/sub-stations
- Communication masts and towers
- Oil & gas plants, rigs and platforms
- Chemical plants
- Marine vessels – Freight and passenger
- Military – Marine; Naval warships, submarines
- Military – Land based; Command centres, weapon systems and field hospitals
- Water pumping stations

SECTION A - OPERATIONAL LEARNING

A.1 Overview & Background

9. This report section A identifies high-integrity applications and industries which are also reliant upon diesel generators operated on an intermittent basis. The report further identifies and describes optimal Mechanical and Electrical, Control and Instrumentation (E, C & I system) designs and best operational practices found within high integrity industries and also for other nuclear jurisdictions and installations.

A.1.1 Operation Modes

10. Electric power generators can be classified in one of three ways depending on their mode of operation:
    - Continuous
    - Prime
    - Standby
11. Continuous and prime power generators are very similar as they function as the main source of power and are designed to operate continuously or for extended periods of time. The major difference between the two is that continuous generator sets are designed to operate continually with a consistent load while prime generators are designed to operate for long durations at variable load.
12. Standby/emergency/back-up types of generator – are run only when there is an outage from the utility grid or the main source of power in a backup situation. Standby/emergency/back-up generators are therefore the main category of generator type utilised for nuclear essential diesel generators.
13. Table 1 shows the operating modes for high-integrity industrial applications with the typical/most common operating modes listed in order of usage (notwithstanding that there may be installations and applications within the industries listed where the operating modes are differently weighted). The table therefore also illustrates which industrial applications are similar to nuclear plant standby/back-up applications.

Table 1: High-Integrity Industrial Applications and Operating Modes

High Integrity Applications and Industries	Operation and Control Modes
Nuclear site back-up power	Standby
Conventional power stations – site/house loads, black start	Standby
Hospitals	Standby
Data Centres (Server Farms/IT centres)	Standby
Airports	Standby
Power distribution monitoring and control centres/sub-stations	Standby
Communication masts and towers	Standby, Continuous

High Integrity Applications and Industries	Operation and Control Modes
Oil & gas plants, rigs and platforms	Prime, Standby
Chemical plants	Standby, Prime
Military - Naval ships, submarines	Prime/Standby
Marine vessels – Freight and passenger	Prime/Standby
Water pumping stations	Continuous/Standby
Military - Land based command centres, weapon systems and hospitals	Prime, Continuous, Standby

A.1.2 Compilation of Relevant Operational Learning Databases

14. Results of information searches for Operational Learning and Experience for High-Integrity Industries Reliant on Diesel Generators are tabulated in:

Appendix A.1: Information Sources for Operational Learning and Experience for High-Integrity Industries Reliant on Diesel Generators.

A.1.3 Common Characteristics across High Integrity Applications and Industries

15. Across high integrity applications and industries, the following common characteristics and requirements are found:

1) High component reliability
2) High availability factor
3) Fast response and start-up times
4) Intermittent demand and operation

A.2 Mechanical Aspects

A.2.1 References

1) APPENDIX A2: Database of Relevant Mechanical Engineering Operational Learning - Incident and Event Reports relevant to Essential Diesel Generators within the nuclear sector.

2) Office for Nuclear Regulation (ONR) Safety Assessment Principles (SAPs) for Nuclear Facilities 2014 Edition Revision 0.

3) European Clearinghouse: Events Related to Emergency Diesel Generators. Summary Report. JRC Scientific and Policy Reports. D Kancev, A Duchac 2013.

A.2.2 Methodology

16. One of the essential precursors in the compilation of international operational learning relevant to EDGs within the nuclear sector, is the safety classification of the associated structures, systems and components (SSCs) on the basis of their safety significance as determined by the fault analysis of the facility (Reference 2 in respect of the UK nuclear sector). It is important that all SSCs are designed, manufactured, installed and then subsequently commissioned, operated and maintained to a level of quality commensurate with their safety classification.

17. One of the key references in the ONR SAPs (Reference 2) concerning this topic is: Safety Classification and Standards paragraphs 158-173 (including ECS.1-ECS.5).

18. Application of ECS.1 requires the safety function to be delivered by the EDGs in the event of a fault or accident, to be categorised based on its significance with regard to safety. The safety categorisation scheme employed should be linked explicitly with the licensee's design basis analysis. Application of ECS.2 requires the EDGs to be safety classified according to their safety significance (i.e. safety category). Application of ECS.3 requires the EDGs to be designed....maintained, tested and inspected according to codes and standards appropriate to the safety classification.

A.2.3 Common Reasons for Failure

19. From the examination of the database (Reference 1), it is clear that the vast majority of the international operational learning data in respect of EDGs relates to the nuclear industry. Nevertheless inclusive in the database are the following Source Reference ID Nos referring to non-nuclear EDG failures:

- 68 – Oil/Gas Industry
- 69 – Marine Industry
- 70 – Marine Industry
- 71 - Hospital
- 72 – Oil/Gas Industry
- 73 – Hospital
- 74 – Healthcare Facilities; Data Centres to Office Buildings & Residential Structures

A.2.4 Common Reasons for Failure

20. There were various causes, contributory factors and root causes of the above EDG failures. In fact source reference ID no 75, Common Reasons for Failure, identified the following nine common reasons for failure:

- Battery failure

- Low Coolant Levels
- Low Coolant Temperature Alarms
- Oil, Fuel or Coolant Leaks
- Controls not in Auto
- Air in the Fuel System
- Ran out of Fuel
- High Fuel Level Alarm
- Breaker Trip

21. Of these nine common reasons, seven are judged to generally result from some inadequate aspect of EIM&T, and the other two to Human Error. Of the seven other source reference ID no's above, four are deemed to have resulted from some aspect of EIM&T, two from Flooding and one from Human Error.

A.2.5 Types of EDG Failures, Causes & Contributory Factors

22. The aim of this sub activity is to review and analyse types of failures, their causes and contributory factors, and shortfalls and relevant good practice (RGP). Identify advice, guidance and lessons learned that is relevant for the nuclear industry.

23. It is worth noting here that part of this aim has been fulfilled above for *Other Industries with similar Reliance/Dependency on EDGs*, and the main general contributor to the EDG failures was found to be some aspect of EIM&T, the only other contributors being Flooding and Human Error. This conclusion regarding a common causal factor of inadequate EIM&T, is also borne out by a study focusing on the analysis of specific operating experience relating to EDGs at NPPs, performed by the European Clearinghouse on OPEX of NPPs, supported by GRS and IRSN (Reference 3). The conclusions of this study are discussed in more detail in the Summary Report for Activity 2. Suffice it to note here that the French concluded from its analysis that a very large proportion of reported events (i.e. 97.6%) occurred during test, inspection and maintenance activities.

24. However, not wishing to pre-judge the outcome of this sub activity, analysis of the events detailed in the database (Reference 1) is discussed in detail below (but excluding those events relating to industries other than nuclear, which have been discussed above). This analysis looked for trends in the types of failures, their causes and contributory factors etc. across Source Reference ID Nos 1-67 in the database (Reference 1).These trends are broadly identified below, along with lessons learned and recommendations, where appropriate, to avoidance recurrence, based upon the associated international operational learning.

A.2.5.1 Flooding (Summary for Source Reference ID Nos 1-13)

25. The massive tsunami (caused by the earthquake) at the Fukushima plant in March 2011, was of very significant relevance to this topic, as the EDG room was flooded resulting in the loss of all but one diesel generator. It was concluded that there was a lack of protection against flooding, and lack of preparation to respond to a severe accident. Recommendations included the installation of air-cooled EDGs, modifying the plants to allow cross-connection of electrical buses and cooling water systems; additional on-site storage for fuel oil sufficient for a 72 hour mission period; permanently installed on-site system; additional redundancy and diversity of EDGs; Loss of Off-site Power (LOOP) and EDG event considered in the safety case; extend current battery capacity and supply; improve flood protection and seismic resilience.

A.2.5.2 Material, Equipment or Component Failures (Summary for Source Reference ID Nos 14-56)

26. The US NRC reported numerous EDG events (e.g. more than a 100 Licensee Event Reports during one 5 month period) and concluded that most appeared to be material, equipment, or component failures but

with no single common trend identified. Causes included:

- Sand entering the engine during maintenance (detected resulting degradation of cylinder liners through periodic chemical analysis of the lubricating oil).
- Fouling in the cooling water heat exchanger.
- Ball bearing failure in the cooling jacket circulating water pump.
- EDG trip on high vibration.
- Low lube oil start time relay.
- Defective low cooling water pressure switch.
- Engine head crack, fuel injection line and rocker arm bolt failed.
- Material change.
- Oil flow to the turbocharger bearing during start up (necessitating a design modification or change in operating procedure).
- Inadequate lubrication during fast starts.
- Main bearings damaged by excessive engine vibration.
- Day tank strainers not been routinely inspected and cleaned.
- Severe damage to engine due to head gasket failure.
- Paint ingress into safety related equipment affecting operability (revise painting procedure to include post-maintenance checks).
- Fouled fuel oil filter.
- Loss of stability of stored oil fuel (e.g. did not meet oxygen accelerated stability criterion) resulting in potential for clogging fuel oil filters.
- Vulnerability to excessive viscosity problems in cold fuel oil.
- Lubrication oil incompatible with low sulphur content fuel.
- Availability of long term air supply.
- Vibration fatigue failure of lubricating oil welded pipe joints (partial penetration welds replaced with full penetration welds).
- Compression fitting failure probably due to a combination of engine vibration and over-tightening during past maintenance (inadequate design or installation of small diameter tubing supports).

27. Specific means of prevention of recurrence is indicated in some cases above. However the following general guidance is given:

- Sound operating practices, coupled with careful maintenance, periodic inspections and testing in accordance with the manufacturer's recommendations, are essential.
- Lubrication before all planned starts; start engine at idle speed, run for 5 minutes and then increase to synchronous speed; increase load in incremental steps; on shutdown, decrease load in incremental steps.
- Conduct bearing inspections (after 20 unplanned starts or 18 months, whichever comes first) to detect any future problems.
- Analyse oil samples on a monthly basis.
- Inspect and replace oil filters and inspect oil strainers on a quarterly basis. Perform a spectrographic analysis of lube oil filter media and any deposits found during the quarterly replacement.
- Verify continuing acceptability of the fuel for emergency use (taking account of the lowest expected operating temperature).
- Diligent removal of all materials/tools used during maintenance.

A.2.5.3 Additional Relevant Good Practices (Summary for Source Reference ID Nos 57-67)

28. (*NB ID No 57 is discussed in the Summary Report for Activity 2*) These source reference ID Nos refer to a mixture of sources of relevant guidelines including the IAEA/NEA Incident Reporting System; Forsmark NPP (*electrical faults-not applicable to this Summary Report*); Station Blackout at Taiwan NPP (*electrical fault-not applicable to this Summary Report*) ; WANO; Newspaper article reporting a Complete Loss of Primary and Secondary Power at Devonport dockyard. The associated additional types of failure/lessons learned are as follows:

- Defective rubber part in a starter motor/ effects of ageing must be considered.
- Premature wear of diesel generator bearings/improved honing of bearing shells during manufacture/increased pressure in the lubrication system and changing the oil type.
- Inability to learn from previous event reports/address shortfalls in maintenance regime

A.3 Electrical, Control & Instrumentation Aspects

A.3.1 Operational Experience & Learning

A.3.1.1 Modes of EDG Failures

29. From Appendix A-3 and Table 4: Failures and Causes, the three main modes of EDG failures are:
    1) Failure to Start
    2) Failure to Load/Run
    3) Failure while Running

30. These common issues can be eliminated with a regular generator maintenance routine performed by properly trained personnel.

A.3.1.2 Main Causes of EDG Failures

31. The main methods available for starting emergency generators are:
    1) Electric starter motors
    2) Compressed air
    3) Hydraulic starting
    4) Inertia starters

A.3.1.2.1 Causes of Failure-to-Start Occurrences

32. The top three reasons found for standby generators failing to automatically start or run are:
    1) Generator START/MODE switch not in left AUTO position.
    2) Starting batteries dead or insufficiently charged.
    3) Fuel filter clogged due to old or contaminated fuel.
33. Other common causes of Failure-to-Start:
    - Air starter system fault
    - Ignored alarms
    - Governor control failures
    - Non-operation of engine block/oil heaters for low ambient temperatures
    - Electrical failures relating to EDG voltage regulation and supply.

A.3.1.2.2 Causes of Failure to Load/Run

34. High level summaries of known Root causes & contributory factors together with known Conclusions and Lessons learned may be drawn from Appendix A.3, Table 3: Failures and Causes.

A.3.1.2.3 Causes of Failure when Running

Gen-set voltage regulator mis-operation.

35. Voltage waveform distortion by non-linear loads can disrupt the operation of gen-set voltage regulators. This problem can be eliminated by using 3-phase sensing digital voltage regulators, pulse width modulation (PWM) in the voltage regulator, and separate excitation power systems like permanent magnet generators (PMG). These steps can make a gen-set almost immune to voltage regulator mis-operation caused by distortion.

Unstable governors.

36. Voltage distortion problems with gen-set voltage regulation equipment may make generator governors unstable and cause frequency disturbances. This can case rectifier misfiring in some active loads such as UPS equipment. Since the advent and adaption of digital excitation controls for modern Gensets, these issues are now relatively uncommon. Furthermore, some manufacturers offer digital governing systems that make engines more stable by sensing engine temperature and re-adjusting governing gains as a function of engine temperature.

Transient voltage and frequency conditions.

37. It is known that gen-set frequency will never be as constant as the utility service, and load changes will cause transient voltage and frequency conditions that can be disruptive to UPS equipment. Setting UPS equipment for slew rates that are achievable with generator equipment, which are typically in the 3 Hz/sec to 5 Hz/sec range, will minimize alarm conditions.

Transfer switch operation and UPS disruption.

38. For early UPS equipment, operation could be disrupted by transfer switch operation, mainly when the transfer switch operated too quickly between energized sources, causing rectifier failures or mis-operation. Adoption and implementation of simple and commonly available “programmed transition” (short time delays in the open position) or fast closed transition transfer switches has solved these issues.

A.3.1.3 Power Transfer and Restoration Methods

A.3.1.3.1 Power System Connection States/Modes

39. The connection modes for the site loads to the on-site diesel generators or the external grid will depend upon the availability of the utility power and the plant operating state. For quick, smooth, stable and reliable provision of power to the plant, the relative states of the plant loads, diesel generators and external grid power need to be known. The site power network can be in the following states/modes:

- Connected to external grid (infinite bus operation)
- Reduced external power connection availability (DG Power take off)
- All power sourced from on-site DGs (Power Islanded/isolated mode)

A.3.1.3.2 Correct Loading and Sequencing Control

40. Load sequencing can help in reducing stresses on an EDG as vital loads are brought on-line. Reducing stresses on an alternator increases operational life and availability.

41. The control of load pickup and removal becomes an important factor in maintaining emergency power supply system stability and power quality.

42. Gensets used for backup power are usually loaded in steps to keep frequency and voltage disturbances within reasonable limits. The ability of the engine to adjust to a step load depends on how fast the turbo-chargers can respond.

43. Industrial loads and applications for prioritisation acceptance are specified with reference to ISO 8528 Performance Class:

Performance Class	Application	Example
Class G1	This applies to generating set applications where the connected loads are such that only basic parameters of voltage and frequency need to be specified.	General-purpose applications (lighting and other simple electrical loads).
Class G2	This applies to generating set applications where its voltage characteristics are very similar to those for the commercial public utility electrical power system with which it operates. When load changes occur, there may be temporary but acceptable deviations of voltage and frequency.	Lighting systems, pumps, fans and hoists.
Class G3	This applies to applications where the connected equipment makes severe demands on the stability and level of the frequency, voltage and waveform characteristics of the electrical power supplied by the generating set.	Telecommunications and Thyristor-controlled loads.
Class G4	This applies to applications where the demands made on the stability and level of the frequency, voltage and waveform characteristics of the electrical power supplied by the generating set are exceptionally severe.	Data-processing equipment or computer systems.

44. Load steps can be accomplished with multiple transfer switches or with other strategies such as timers on motor starters or BAS integration. The load with the largest starting "inrush" current would need to be sequenced to start first, then adding remaining load steps using the same largest motor first concept. The load steps in the sequence should be long enough for the alternator to recover before adding the next step. This is typically a couple of seconds for larger equipment loads.

45. When large continuous motor loads are present, proper load sequencing and managing the starting KW of the generator can assist in reducing the size of the generator.

46. This concept works when the large motor loads are started and then run continuously. But when on/off cycling large motor loads exist, the system still needs to be sized as if it were the last load to start with the other loads already energized. However, with cycling motor loads, reducing the starting current (and starting kW) by use of a solid-state starter with bypass contact can also help reduce the stresses on the alternator.

47. Furthermore, consideration of the load criticality and priority needs to be when sequencing loads. For example in a hospital, the emergency system loads consisting of the life safety and critical branch loads are typically the highest priority because they must be online within a required 10 seconds. Industrial and application code requirements for load priority can also have an effect on generator system sizing.

48. Depending on the size of system, the largest load first method may still be applied after code required loads are energized to help in overall system sizing.

A.3.1.3.3 Soft-Loading Transfer Switches

49. Soft-loading transfer switches provide smooth transfers between utility power and generator power and also reduced stresses and hence potential reliability issues for all components in the power system. During soft loading operation, the generator and the utility operate in parallel for about 5 seconds while the power is gradually transferred from the utility to the generator.

50. Typical industrial applications which benefit from installations soft-loading transfer include hospital stand-by power generators. In such applications the generator typically requires monthly testing. These tests

involve power transfer operation checking to ensure that there are no disruptions in power, no surges or flickers when the unit is started and engaged.

A.3.1.4 Wet Stacking

51. Wet-stacking is a common problem with diesel engines which are operated with little or no loads applied.
52. Frequent wet stacking can shorten the life of a generator, increase maintenance costs, and increase the level of emissions produced.
53. Wet stacking is caused when diesel generators are run under light loads or for short durations where the engine is not able to get up to operating temperature. If the engine does not get up to the proper operating temperature, unburned fuel gets exhausted and accumulates in the exhaust system and can also foul the fuel injectors. Wet stacking can therefore be alleviated by running the generator under a high load for several hours in normal operation or during periodic standby generator exercising.
54. Properly sized and selected generators should have an available load of at least 70% to 80% of the rated output of the generator. Diesel generators that run for extended periods of time with less than 40% load tend to have problems with wet stacking.
55. Having an adequate building load available for the generator testing is the best way to ensure that the generator will operate properly, but that is not always easy to do. For hospitals, data centres, and other facilities with critical loads, it is not always practical to use building loads for generator exercising.
56. In order to avoid potential wet stacking conditions, possible remedies include:
    - Application of prolonged high load exercising routines during scheduled generator testing.
    - A permanent load bank incorporated into the system design to add necessary load to the system during routine testing. These an additional investment if they are permanent but can alternatively be rented if calculated to be more cost-effective.
    - Identification of any off-hours running where low loading occurs and therefore consider application of supplementary load banks
    - Provisions for a portable load bank to be easily connected during routine maintenance may also be applied.
    - Supplemental loads can be provided by connecting noncritical building loads to the generator through manual transfer switches that can be switched onto the generator for exercising or testing.
57. A preference is to size the load bank for full generator rating with the capability of adjusting it down. This allows for both maintaining a minimum 40% load and full load testing of the generator.
58. Auxiliary loads, either automatic or manual, can be very beneficial to the facility. This would typically consist of a large mechanical load served by a separate Auto/Manual Transfer Switch that could assume the load necessary to avoid wet stacking. On a standby generator this may be a non-essential load that could be added to the system when capacity is available, or be load shed when reaching the limits of the rated genset. For example, a chiller and associated components may be an available but non-required emergency load for hospital or other applications.
59. Regardless of any designed opportunities to eliminate wet-stacking effects, the maintenance and testing personnel need to be aware of and take advantage of these provisions. Adequate education and communication with the maintenance staff is necessary to ensure that the intended methods to avoid wet-stacking are implemented.

A.3.2 Identified Good Practices from Industry

A.3.2.1 Functions for Availability & Reliability

- Qualified high-reliability components.

- High reliability redundancy design features.
- Spurious trip resistance from transients.
- Trip systems required to be highly environmentally resistant and robust.
- Diesel fuel cooling.
- Manual over-ride functions.
- Back-up field control functions and panels.
- Ability to operate continuously at 110% of rated load for 24 hours.
- Optimised load sequencing system.
- Remote starting functions.
- Start and stop conducted by automatic signals.
- Over-speed tripping device (electromagnetic pickup) installed separately from the governor.

A.3.2.2 Cold Start Capability

60. Cold start capability and reliability can be increased by secondary functions which maintain or raise the generator's temperature in cold ambient conditions. These functions and sub-systems include:

    1) Engine water jacket/cooling system heaters
    2) Sump oil heaters
    3) Pre-lubrication pump
    4) Diesel fuel heaters
    5) Alternator winding heaters

61. For reliable starting, the diesel engine is kept warm using electrical heaters. These can take the form of a heater on each side of the engine using natural convection to circulate the water, or a single heating unit with a small central heating style pump to circulate the water. The heaters are thermostatically controlled to keep the temperature above 40°C; should the temperature fall below this value, a Common Alarm is generated. The heaters are automatically switched off when the engine runs.

62. To keep the engine bearings well lubricated for start-up, a pre-lubrication pump circulates lubrication oil every 12 hours for approximately 5 minutes.

63. The alternator windings are kept warm using a small heater to ensure that the insulation remains dry and effective. The heater is automatically switched off when the engine runs.

A.3.2.2.1 Electrically Assisted Cooling Systems

64. A diesel engine generates a large amount of waste heat, typically 55% of the engine rating. This waste heat is required to be dissipated for efficient operation and reduce over-heating shut-downs.

65. The heat is dissipated in the primary and secondary water cooling circuits, with appropriately sized radiators and matching cooling fans can be therefore be quite large and so the fan power requirements need to be considered.

66. For a Low Voltage generator, it is fairly straightforward to obtain electrical power from the generator output to drive one or more electric cooling fans; however, a High Voltage generator would need local HV switchgear and a step-down transformer to drive electric cooling fans. It is possible to obtain the fan supplies from the auxiliary supply to the genset if this supply is re-supplied by the genset soon after start-up.

67. A direct cooling fan drive from the engine crank-shaft has advantages for a High Voltage generator in that radiator cooling does not require local HV equipment or dependable auxiliary supplies. However, beyond a genset size of 3MVA, the radiator and direct drive cooling fan become too large to be practicable, and

electric cooling fans are necessary. Furthermore, if the radiator(s) are to be remote from the engine, then electric cooling fans have to be implemented.

68. Water cooled heat exchangers may be used to dissipate the engine waste heat if there is a suitable water cooling system in the facility. The pumps in this system would need to be re-supplied by the genset in order to assure cooling while the machine is running.

69. In addition, the heat is radiated from the engine surface, typically 4% of the engine rating. A direct cooling fan drive from the engine crank-shaft has the advantage that air is drawn across the machine before being expelled through the radiator. Electric fan drive systems may require an additional fan to cool the engine compartment.

A.3.2.2.2 Emergency Operation Mode

70. To ensure power availability during mission critical (e.g. military) operations, it is imperative that emergency power supply components and systems are continuously in operation as the highest priority. Therefore military generators incorporate emergency over-ride controls for use in extreme situations, variously referred to as:

- ‘Battle Over-Ride’,
- ‘Battle-Short’,
- ‘All Else Fails’, or
- ‘Run to Destruct’.

71. When generators are placed in this mode, the normal scope of protection and shut-down controls will be disabled and the generator will be allowed to run-on despite any faults which could damage or reduce the operational life of the generator. Typically the few remaining shut-down alarms are safety related and would include; over-speed shut-down, high oil pressure shut-down and over-voltage shut-down.

A.3.2.2.3 Standby Conditioning

72. The diesel engine and alternator operate intermittently; typically once a month for a load test, and in the rare event of a loss of site electrical power.

73. For reliable starting, the diesel engine is kept warm using electrical heaters. These can take the form of a heater on each side of the engine using natural convection to circulate the water, or a single heating unit with a small central heating style pump to circulate the water. The heaters are thermostatically controlled to keep the temperature above 40°C; should the temperature fall below this value, a Common Alarm is generated. The heaters are automatically switched off when the engine runs.

74. To keep the engine bearings well lubricated for the start-ups, a pre-lubrication pump circulates lubrication oil every 12 hours for approximately 5 minutes.

75. The alternator windings are kept warm using a small heater to ensure that the insulation remains dry and effective. The heater is automatically switched off when the engine runs.

A.3.2.3 Further Good Practices and Military Applications

76. For military applications, the key requirement is to ensure power availability during missions which are inherently conducted under demanding conditions and harsh environments.

77. The power systems are therefore required to be reliable and available under such external events as physical damage and extremes of environments (wide ambient temperature range, high heat, freezing, humidity, and high EMC/RFI levels). The equipment and configurations must also have fault-tolerant operation, improved fault detection and self-diagnostic capabilities when the system is operating normally, so that remedial actions can then be actioned upon the appearance of a fault.

78. To ensure high availability and reliability, the following features and designs are employed:

A.3.2.3.1 Redundant Logic

79. To ensure maximum reliability, redundant logic such as parallel digital/analogue logic trains and multi-channel sensors can be employed. The parallel logic train provides resistance to common cause failures. Sensors can also be designed with redundancy, such that critical readings such as oil pressure and engine speed with sensors installed in groups of three and using logic based on a "2 out of 3" principle. A failure or incorrect output of a single sensor would not result in EDG shutdown; signals need to be received from at least two of the three parallel sensors for automatic actuation of the protection system.

A.3.2.3.2 Redundant Levels of Controllers

80. The basic operation of earlier technology diesel engines did not include or rely upon electrical controls and associated power supplies for continuous running. Controls were basic mechanically adjusted fuel supplies and mechanical governors. Starting could be by pneumatic means and stopping by a fuel stop valve/lever.

81. Contrasting to this, modern diesel engines employ programmable Electronic Control Units (ECUs) which enhance fuel efficiency, reduce emissions of pollutants and provide various enhanced control and monitoring functions, including; monitoring numerous engine performance parameters (temperatures, air flow etc.) and emissions produced (exhaust gas temperatures). These parameters are fed into complex software control algorithms within the main micro-controller which output very high speed fuel control commands to the electronic diesel injectors.

82. Due to the requirements for the features and functions afforded by electronic controls and actuators together with mandatory pollution control legislation, present diesel generators on the market can no longer incorporate fall-back control modes which do not include electronic controls and associated power supplies. This presents a single point of failure risk, as should a total ECU failure occur, operators have no manual controls for engine restart, throttle, or other functions and in effect the engine fails.

83. A guiding principle for mission-critical equipment design is that the system is only as reliable as its components. The entire system must be "fault tolerant" – able to remain functional in the event of a failure of one of the components. Adding redundant components significantly increases both fault tolerance and system reliability. Therefore the single point of failure risk can be mitigated primarily by 3 methods: 1) Incorporate an additional monitoring unit for key parameters (e.g. as required for classified marine installations), 2) Incorporate a second control and monitoring unit. 3) Apply 1 & 2 together.

1) Additional monitoring, (Engine Monitoring Unit - EMU)

84. The EMU acts as a safety system for independent redundant monitoring of key engine signals. For this, a second sensor set is installed on the engine which allows for monitoring of these key parameters, normally including engine speed and lubricating oil pressure. These signals can then be utilised for independent alarms and activation of emergency shut-down.

85. The use of an independent EMU can also allow for the employment of a diverse design from the main ECU.

86. Furthermore, the EMU permits an expansion to the range of signals for monitoring engine measuring points such as, oil mist detection and individual exhaust monitoring.

2) Redundant monitoring and control unit, (ECU) together with switch-over unit

87. Installing a second redundant ECU can increase reliability (assuming that the failure is a random hardware failure and not the result of a design or manufacturing error, which may cause identical failures in all identical redundant components).

88. For this, a second sensor set is installed on the engine. The ECU engine control unit is used as a main and backup controller. Because the injectors and high-pressure fuel control block are not (and/or cannot be) installed redundantly, triggering of these actuators must be switchable between the two controllers by a switch-over unit between the two ECUs.

3) Engine Monitoring Unit (EMU) + Engine Control unit (ECU) + Switch-over unit

A.3.2.3.3 Redundant Power Supplies for Control Circuits

89. To ensure that the electronic and digital generator controls and circuits are continuously supplied with power, redundant and fail-over supplies are incorporated in military generators. Typically genset control systems operate from a 24VDC supply, which for naval marine applications can be redundantly provided from:
    1) Ship's 24 DC bus
    2) Dedicated local DC battery bank for genset control circuits/panels
    3) Ship's 230 VAC bus through AC-DC power converter
    4) AC output of generator fed back into a second AC-DC power converter
90. The output of each power source is fed via diode steering or basic relay switching onto an internal 24VDC bus within the control system. This allows for reliable and automatic fail-over in the event of a power source becoming unavailable. It also allows for generator black-ship/black-start capability.
91. Furthermore basic power supply fault indicators and circuit protections such as below may be incorporated:
    1) Under-voltage detect alarms on each supply line (or a relay for basic indication of a supply's presence)
    2) Over-voltage detect alarm/disconnect circuits on the output of each supply (as power supply outputs don't always go low when they fail)
    3) Use of output current limiting circuits instead of fuses, which drop the output faster than the time required for a fuse to blow. This eliminates a fuse as first stage output protection and so reduces component count and a potential failure point. Furthermore current limiting automatically resets after a surge and allows supplies to resume.
    4) Use of simpler linear power supplies instead of solid-state switch mode power supplies (if relatively larger size and weights are usually not a concern).
    5) Use of high reliability designed and qualified battery chargers for internal control panel battery
    6) Inclusion of internal panel battery charge and conditioning monitoring circuits

A.3.2.3.4 Damage Reconfiguration / Restoration

92. Power detection and management system to detect battle and fire damage to power circuits and automatically re-route power to main mission critical equipment supply busses.

A.3.3 Design Practices for Reliability and Long Life

3.1.1 Optimal Generator Sizing

93. The correct rating of generators is vitally important to ensure performance efficiency, reliable operation and optimal maintenance costs. Significantly oversizing a generator above the standard load requirements, for example to cope with additional harmonic loads, will reduce performance efficiency and reliability and also increase capital investment, operation and maintenance costs.

A.3.3.3.1 Surge loads

94. Surge loads should also be considered in properly sizing a generator system. Such peak load demands can occur when large electrical motors are in the process of starting up as they can draw a momentary surge demand that is five times larger than their normal operating demand. Such potential peak loads should therefore be considered across the generator system from sizing to cope with the loads and application of load scheduling.

95. Another important factor to consider in sizing a generator system is the fact that generators achieve their best fuel economy, least engine wear and most importantly least wet-stacking/clogging when operating at a load range of 70% to 80%. Sizing for this loading range therefore ensures greatest potential availability for stand-by generators when instantaneous operation is demanded.

A.3.3.3.2 Unbalanced 3 Phase Loads

96. Legacy EDG systems may have been originally rated for traditional load types prior to the use of active power electronic and may therefore be subject to potentially unbalanced 3 phase loads or loads with high Total Harmonic Distortion (THD).

A.3.3.3.3 Harmonic Loads

97. Harmonic currents can cause internal heating of the generator, limiting its capability and shortening its life. For electrical systems where the harmonic content seen by the generator is high, significant de-rating of the generator may be required to prevent overheating or premature generator failure.

98. It is now common for generators to have nonlinear loads of active power electronics components which can have significant content of harmful harmonic currents. These include UPS's, frequency converters and motor Drives (Variable Frequency Drives, VFDs). Also such loads that impose a leading power factor on the power source do not usually present problems when powered by the utility. However, if the generator is the power source and due to its inherently higher impedance, the leading power factor can cause instability or even failures.

99. Furthermore, if the generator is not sized and selected properly, both the generator and any "harmonics-rich" loads can both experience problems while operating from generator power.

100. It is always better to mitigate the harmonic through proper design, rather than to significantly oversize the generator to compensate for harmonic affects. Harmonic or other power quality issues should first be mitigated to limit the de-rating or oversizing of the generator. For example, provide filtering or other harmonic attenuating options such as isolation transformers at the source of distortion. Where loads are connected line-to-line to the generator bus, without a neutral connection or supplied through delta-wye transformer, the occurrence of triplen harmonics, caused by the load, are not seen by the generator.

101. When a few large nonlinear loads are connected, the generator experiences more disturbances than when only a few small VFDs or UPS are present in the system. Therefore careful consideration shall be given to the unit size and nonlinear loads connected relative to the generator size. In general, the generator should be sized so that nonlinear loads will not exceed 40% of its capacity.

102. In cases of higher reverse kVAR's power flows into the generator, as caused by leading power factor loads (e.g. UPS and its filters), the alternator may drive into over voltage condition.

103. Reverse VAR (loss of field) protection for alternators can be fitted and is also effective in preventing pole slipping when properly tuned for the specific generator in use. However settings that are too conservative will cause nuisance shutdowns of the generator — and possibly the system — while settings that are too aggressive won't provide enough protection. Therefore the influence of higher reverse kVAR's power flows due to non-linear loads can adversely affect this balance.

104. The following design guidelines are used in industry to minimize or eliminate compatibility issues between UPS systems and standby generators:

- Continue design practices that have been successful in the past. For example, select gen-sets with low-temperature-rise alternators. These larger alternators also provide better motor-starting capacity and greater resistance to voltage waveform distortion.

- Specify low sub-transient reactance for alternators, digital excitation control, and voltage regulator power supplies with PWM. UPS applications also generally require electronic isochronous governors.
- Always use closed-transition or open-transition, delayed-neutral position transfer switches.
- Specify state-of-the-art UPS systems wherever possible. Later designs tend to reduce total harmonic distortion and minimize rectifier sensitivity to frequency changes. These newer systems also tend to have greater adjustability in dealing with generator and UPS interaction issues.
- Understand the alternator's ability to absorb reactive power, and determine how much corrective kVAR is in the load. Determine which specific operational sequences will produce enough reverse VAR to cause problems and then specify what the system needs.
- Design proper load sequences by connecting the loads which require reactive power first, before the UPS ramps on to the generator or switch off the filters at low UPS loads levels.

3.1.2 Alternator Selection

105. The correct sizing and selection of the electrical power generating alternators of the genset is imperative for long and reliable operation.

106. A key requirement for alternator selection and specification is to specify high temperature ratings for alternator windings and associated wiring.

107. For example; high integrity emergency alternators are built with high temperature 190°C NEMA Class H wire and insulation. Maximum operating temperatures should not exceed lower Class F levels. This provides an extra margin of thermal capability for standby applications with unbalanced phases and non-linear loads.

3.1.3 C &I Hardware Design Best Practices

108. The following hardware design best practices and requirements are implemented in diesel genset designs to allow for optimum reliability and component life:

A.3.3.3.1 Electrical Interfaces

- Corrosion protected terminals – All exposed electrical terminals are coated for corrosion protection and enclosed within a boot for mechanical protection.
- Dual wire engine sensors – All engine sensors are changed from industry standard single wire to dual wire types. This reduces circuit failure due to unreliable ground return circuits.

A.3.3.3.2 Wiring Techniques

- Fully enclosed wiring system – All wiring is enclosed in flexible plastic conduit to prevent damage to harnesses and connectors.
- Waterproof and airtight electrical cable connectors.
- Coated circuit boards – All printed circuit control boards are conformal-coated or encapsulated to prevent environmental corrosion and mechanical damage.
- Surge protection – Built-in surge suppressors enhance protection from voltage spikes. This increases the reliability of the generator and its controls.
- Electrical Magnetic Compliance/Interference shielding – Control units are EMC/EMI tested and equipped with magnetic shielding to protect the control system.

- Fuse protection – Control systems have properly rated and discriminated fuse protection at board and system level.

SECTION B - EXAMINATION, INSPECTION, MAINTENANCE AND TESTING (EIM&T)

B.1 Overview & Background

109. The reliability of emergency diesel generators (EDGs) can be one of the main factors affecting the risk of core damage from a station blackout event. Thus both attaining and maintaining the high reliability of EDGs at nuclear power plants, contribute greatly to reducing the probability of station blackout. One of the key factors associated with the maintenance of such high reliability is the adequacy of the associated examination, inspection, maintenance and testing (EIM&T) regime.

110. The fundamental deliverable for this Activity is a database of relevant good practice in terms of undertaking EIM&T on diesel engines and generators, and this is provided at Reference 1.

111. This Summary Report of the main findings of the study is, inter alia, addressed under the headings of the various sub activities below.

B.1.1 Methodology

112. One of the essential precursors in the formation of a suitable and sufficient EIM&T regime, is the safety classification of the particular structures, systems and components (SSCs) on the basis of their safety significance as determined by the fault analysis of the facility (Reference 2). It is important that all SSCs are designed, manufactured, installed and then subsequently commissioned, operated and maintained to a level of quality commensurate with their safety classification.

113. One of the key references in the ONR SAPs (Reference 2) concerning this topic is: Safety Classification and Standards paragraphs 158-173 (including ECS.1-ECS.5).

114. Application of ECS.1 requires the safety function to be delivered by the EDGs in the event of a fault or accident, to be categorised based on its significance with regard to safety. The safety categorisation scheme employed should be linked explicitly with the licensee's design basis analysis. Application of ECS.2 requires the EDGs to be safety classified according to their safety significance (i.e. safety category). Application of ECS.3 requires the EDGs to be designed....maintained, tested and inspected according to codes and standards appropriate to the safety classification.

B.1.2 Compilation of Relevant Good Practice Database for EIM&T

115. This second section of the report identifies relevant good practice for undertaking Examination, Inspection, Maintenance and Testing (EIM&T) together with identifying systems and OEMs relevant in the safe and reliable operation of essential diesel generators. The report also includes advice appropriate to the optimisation of run-cycles and considerations regarding ageing and obsolescence issues.

B.2 Mechanical Aspects

B.2.1 Relevant International Codes and Standards

116. The aim of this sub activity is to identify international codes and standards which apply to essential diesel engines and generators, including any recent changes in UK legislation.

117. The fundamental UK guidance for the EIM&T of items important to safety is in the form of a UK Technical Assessment Guide published by ONR (Reference 3). This directly addresses those ONR SAPs which relate to in-service and through life EIM&T (i.e. EMT.1-EMT.8). Clearly EDGs fall into the category of 'items (SSCs) important to safety'.

118. There are some subtle changes to ONR SAPs EMT.1-EMT.8 in the 2014 version of the SAPs

(Reference 2) when compared with the 2006 version. These are:

- EMT.2 Frequency: as defined in the safety case, has been added.
- EMT.3 Type Testing: now refers to conditions equal to, at least, the most onerous for which they are designed, as opposed to the most severe expected in all modes of normal operational service.
- EMT.4 Validity of equipment qualification: Continuing, has been added.
- EMT.6 Reliability claims: SSCs important to safety, has been removed and replaced by (including portable equipment).
- EMT.7 Functional testing: SSCs important to safety, has been removed.
- EMT.8 Continuing reliability following events: SSCs important to safety has been removed. Should be inspected and/or re-validated after any internal or external event has been removed and replaced by after any event. That might have challenged their design basis has been removed and replaced by continuing reliability.

119. These subtle changes were obviously pre-empted by the events of 2011 at the Fukushima plant, where the massive tsunami caused by the earthquake flooded the EDG room, and resulted in the loss of all but one of the EDGs. (More detailed reference to Fukushima is included under Activity 1). Clearly the intention of the changes to the guidance for the EIM&T of SSCs, is to ensure (as far as is reasonable practicable) that EDGs, inter alia, will be inspected and/or re-validated after any event (both design basis and beyond design basis) that might have challenged their continuing reliability.

120. Standards are set by national bodies including the IEEE, ASME (USA), RCCE and RCCM codes (France), the CSA (Canada), KTA (Germany), GOST and ROSTECHNADZOR (Russia) and YVL (Finland). The author is not aware of any other recent changes to international codes and standards which apply to essential diesel engines and generators. For example, the Institute of Electrical and Electronic Engineers (IEEE) Standard 387-1995 (Reference 4 & source reference ID No 14) is a benchmark that is widely referenced for principal design criteria and qualification and testing guidelines, to ensure generators meet performance requirements. However it has not been revised since December 1995. Also the Nuclear Safety Standards Commission KTA has a safety standard which applies to EDGs (Reference 5 & source reference ID No 7). However it has not been revised since June 2000.

B.2.2 Systems Relevant to Safe and Reliable Operation

121. The aim of this sub activity is to identify the extent of systems relevant in the safe and reliable operation of essential diesel generators and associated standards in terms of design code, inspection and maintenance regimes. A 'brain storming' list of systems and fault parameters relating to this sub activity is provided in Appendix A of the ONR Specification for this Contract (Reference 6).

122. A review of EDG events from world-wide operating experience on Nuclear Power Plants (NPPs) is one of the pre-requisites to the provision of an understanding of systems relevant to their safe and reliable operation. Such a review was undertaken in 2013 by the Regulatory Support Department (RSD) of Amec (Reference 7). The review covered incidents that have occurred over the past 30 years of operating experience recorded within the International Event Report's (IRS) database. A review of World Nuclear News, the US NRC database, as well as the internet more generally was also conducted.

123. A number of common themes relating to EDG failure were identified (Reference 7) relating to both the diesel engine and voltage generator and their associated support systems, which were summarised as follows:

- EDG start/control issues relating to air starter system and governor control failures associated with use of inferior components, poor maintenance and contamination and leaks.
- Engine mechanical failures because of loss of lubrication through contamination, vibration fatigue induced leaks of small bore pipework supporting engine services and internal scoring of engine interiors from abrasive particulates.
- Engine cooling system failures due to jacket water heat exchanger fowling and issues relating to loss of heat transfer, internal and external corrosion of sea water cooling pipes/valves and fatigue leading

to leaks. Additional issues are linked to temperature regulation in the cooling system due to failure of temperature sensors or regulator valve mechanical failures.

- Fuel oil/transfer system failure due to loss of fuel specification and degraded/fatigue failures of pipe joints and valves leading to fuel leaks. Degraded fuel or use of bio or low sulphur fuels can lead to incompatibility issues with engine components and formation of impurity products that can severely impair engine operability.
- Electrical generator/breaker failures leading to loss of EDG function covering loss of voltage regulation, grid disturbance and mal operation of automatic circuit breakers.

124. A further study focusing on the analysis of specific operating experience relating to EDGs at NPPs, was performed by the European Clearinghouse on OPEX of NPPs, supported by GRS and IRSN (Reference 8). Four different databases were screened for EDG related events over a time period of roughly 20 years, namely: GRS (Germany), IRSN (France), IRS (IAEA) and US NRC. A trend analysis was performed of the 676 events considered, and the main categories in which EDG failures were classified were as follows: type of failure, failure modes, the main causes for the failure, the affected components, and the manufacture and type of diesel engine. Based on the analysis, recommendations were grouped into the following 6 main categories:

- Preventative maintenance and testing – training of operating and maintenance personnel, and control and supervision; EDG run test typically 4 weekly for at least 1 hour.
- Manufacturing and spare parts – improved anticipation of component obsolescence
- Operating Experience Feedback – increased attention to generic character of some failures, and the risk of common cause failure among multiple EDGs; internal and external disturbances in the plant electrical systems, causing voltage transients.
- Protective devices – periodic inspection of the EDG safety bus protective devices; devices required to start the EDGs should be supplied from a UPS.
- Reliability – electrical and diesel engine protection systems should be highly reliable, through 2 or 3 input signals with a voting logic of 2 out of 2 or 2 out of 3.
- External Events – regularly review the plant design basis for potential risk from external events, as the original assumptions may become insufficient.

125. It is particularly important to note that the French concluded from its analysis that a very large proportion of reported events (i.e. 97.6%) occurred during test, inspection and maintenance activities.

126. There is a synergy between the types of failure identified in the above bulleted lists derived from References 7 & 8, and the extent of systems relevant in the safe and reliable operation of EDGs detailed in Appendix A of the ONR Specification for this Contract (Reference 6). The main difference is that Appendix A identifies the importance of design code features such as supply buildings and ventilation systems, and limiting operating conditions, as well as test, inspection and maintenance activities. Thus that part of the aim of this sub activity, to identify the systems relevant in the safe and reliable operation of EDGs, has been satisfied above. What remains is to identify the associated standards in terms of design code, inspection and maintenance regimes.

127. Identification of the associated standards in terms of design code, inspection and maintenance regimes, can be made by recourse to the database of relevant good practice in terms of undertaking EIM&T on diesel engines and generators, and this is provided at Reference 1.

128. With respect to design codes, and as stated above, IEEE Standard 387-1995 (Reference 4) is a benchmark that is widely referenced for principal design criteria (and qualification and testing guidelines), to ensure generators meet performance requirements. Its source reference is ID No 14 in the database of RGP (Reference 1). Other standards detailed in the database (Reference 1) which refer to aspects of the design of EDGs are source reference ID Nos 4, 7, 16, 19 (air force), 21, 43 (hospitals, public places etc.), 44, 45.

129. Standards detailed in the database (Reference 1) which refer to aspects of the inspection and maintenance of EDGs (NB this does include testing in general, however a specific aspect of testing is discussed in detail under the next heading) are source reference ID Nos 1-7, 9-11, 15-24, 26-29, 32-37, 41, 43 and 45.

B.2.3 EIM&T Relevant to Infrequent, Short Operational Run Times

130. The aim of this sub activity is to identify Original Equipment Manufacturers (OEMs) responsible for the supply of equipment to the nuclear industry, and seek advice regarding the adjustment of inspection and maintenance regimes to accommodate the infrequent, short operational run times of the diesel engines. Also to formulate advice appropriate to the optimisation of run-cycles (frequency and duration) to ensure confidence is maximised in the reliability and operability of the diesel engines whilst minimising premature failures.

131. Standards detailed in the database (Reference 1) which refer to a specific aspect of the testing of EDGs are source reference ID Nos 12-14, 17, 20, 22, 24, 26, 27, 30-32, 38-42, 47, 48. Two of these have been sampled to provide guidance concerning the adjustment of the EIM&T (in particular the testing) regimes to accommodate the infrequent, short operational run times of the diesel engines.

132. For EDGs, IEEE Standard 387-1995 (Reference 4, ID No 14) gives details for Factory Production Testing, Qualification Requirements, and Site Testing. The Site Testing includes Site Acceptance Testing, Pre-Operational Testing and Periodic Testing. Clearly it is the Periodic Testing Guidance which is pertinent to this sub activity. Table 4 of Reference 4 lists the minimum periodic test parameters to be measured (pressures, temperatures, electrical and levels) pre-start/during test/post-test. Periodic tests shall consist of:

- Availability Tests to demonstrate the continued capability of the EDGs to both start and accept load – Each EDG unit shall be started and loaded at least once a month (slow-start and load-run test).
- System Operation Tests to demonstrate the ability of the EDG unit to perform its intended function under simulated accident conditions. These tests shall be performed at shutdown/refuelling outages once every 2 years.
- Independence Verification Test to be performed subsequent to any modifications where EDG unit independence may have been affected, or every 10 years during a plant shutdown or refuelling outage, whichever is the shorter.

133. These tests shall be preceded by a pre-lube period, and should be in general accordance with the OEM’s recommendations for reducing engine wear, including cool-down operation at reduced power followed by post-operation lubrication. Unless otherwise noted, these tests should be performed at a power factor as close as practical to the design load factor as plant voltage permits.

134. The Nuclear Safety Standards Commission KTA safety standard, which also applies to EDGs, (Reference 5, ID No 7) gives guidance for Periodic Testing. It begins by emphasising that in service tests are not normally to be undertaken simultaneously on several trains. Tests should be repeated in the event of a start-up failure or failure during a test, following the identification of the cause and removal of the defect. If the cause cannot be clearly identified a more frequent test interval shall be specified. A function test run including start up and power load, should be conducted for a duration of 2 hours, followed by 1 hour at 80% of rated continuous power. The test interval should be 4 weekly and prior to every start-up of the power plant following longer outages (e.g. refuelling). Start-up shall be triggered at least once a year by disconnecting the bus coupler between service equipment and the EDG bus coupler. A test run should be undertaken once a year (after a function test run) at overload power capacity for ½ hour (i.e. 1 train every 3 months for a 4 train EDG system). Control and Instrumentation equipment, whose function is not checked during the test runs, should be tested at least every 4 years (i.e. 1 train per year for a 4 train system). Adherence to the specific requirements of the fuel, and the changes it undergoes in the fuel storage tanks, shall be checked on representative samples during initial fill; following each refill; and at intervals of 6 months.

135. From the descriptions taken from the two sample references above, it is clear that the testing of EDGs should be both comprehensive and frequent (i.e. 4 weekly).

B.2.4 Ageing and Obsolescence

136. The aim of this sub activity is to review considerations regarding how the international community is dealing with ageing and obsolescence issues in respect of EDGs, and how this is affecting maintenance and contract control.

137. The objective of the IAEA Safety Guide on Ageing Management for Nuclear Power Plants (Reference 9) is to provide recommendations for managing ageing of SSCs important to safety in nuclear power plants, including recommendations on key elements of effective ageing management. Clearly EDGs are SSCs important to safety.

138. Nuclear power plants in general experience both physical ageing of SSCs (which results in degradation), and obsolescence of SSCs (becoming out of date in comparison with current knowledge, standards and technology), and EDGs are no exception to this. Evaluation of the cumulative effects of both physical ageing and obsolescence on the safety of nuclear power plants is a continuous process and is assessed in a periodic safety review. Effective ageing management is in practice accomplished by coordinating existing programmes, including maintenance, in-service inspection and surveillance, technical support and research and development. A systematic approach is required, coordinating all programmes and activities relating to the understanding, control, monitoring and mitigation of ageing effects. Ageing degradation is studied and managed at the structure or component level. However, if required by safety analysis, the ageing management programmes for individual structures and/or components may be integrated into an ageing management programme at the level of systems. Management of obsolescence is a part of the general approach for enhancing nuclear power plant safety through ongoing improvements of both performance of SSCs and safety management. There are several types of obsolescence, namely SSCs out of date in comparison with current knowledge; standards and regulations; and technology.

139. Examples of significant ageing mechanisms and susceptible materials and components are given in Annex 3 of Reference 9. Some of these such as: fatigue (low and high temperatures) of rotating equipment supports and piping; mechanical wear of rotating equipment; insulation embrittlement and degradation of cables, motor windings, transformers; oxidation of relay and breaker contacts, lubricants, insulation materials associated with electrical components are applicable to EDGs.

140. In terms of how the international community is dealing with ageing and obsolescence specifically in respect of EDGs, recourse is made to the database of relevant good practice of EIM&T regimes (Reference 1). Clearly ONRs SAPs in respect of guidance for EMI&T regimes in support of nuclear facilities, implicitly apply to ageing and obsolescence, as EMT.5 refers to Commissioning and in-service inspection and test procedures should be adopted that ensure initial and continuing quality and reliability, and EMT.6 refers to EMI&T regimes for SSCs in-service or at intervals throughout their life. Also it is expected that all EMI&T programmes referred to in the source references, will implicitly include some provision for the management of ageing and obsolescence (which, as stated above, is one of the key topics to be addressed in a periodic safety review).

141. Examining the database of RGP (Reference 1), there are no explicit references to ageing and obsolescence in the topic descriptions. Recourse to the two standards sampled above under the heading Systems Relevant to Safe and Reliable Operation (i.e. References 4, 5). Whilst Reference 5 does not refer explicitly to ageing and obsolescence, Reference 4 does include a short section dedicated to ageing.

142. IEEE Standard 387-1995 (Reference 4 & source reference ID No 14) recommends that components and assemblies within the scope of the EDG should be classified as:

a. Safety Related: Required to enable the EDG to meet its capabilities in terms of the specified design conditions of the Unit. These require consideration of ageing as a potential for causing common mode failures. Examples may include the governor, generator, cable, excitation system, engine, starting air solenoid valves, and sub component items or materials such as gaskets and seals (whose failure will degrade Unit performance), insulation and bearings. Those components and assemblies with potential age-related failures should be qualified by testing or analysis or a combination thereof. Components with a resultant identified qualified life less than the overall qualified life should have a maintenance/replacement interval defined.

b. Non Safety Related: Require verification that they will not degrade the safety related function. This may be accomplished by testing or analysis. Examples may include generator resistance temperature detectors (RTDs), neutral grounding equipment, space heaters, starting air compressors and drives, keep-warm heaters and pumps, and those gaskets and seals whose failure will not degrade Unit performance.

B.2.5 Events Associated with Inadequate EIM&T

143. The aim of this sub activity is to identify (from the Activity 1 study) events where inadequate EIM&T associated with diesel generators was deemed to be a root/contributory cause of the event.

144. Reference to the Summary Report for Activity 1, under the heading of Other Industries with similar Reliance/Dependency on EDGs, indicates that in general terms the most common cause of EDG failures is some inadequate aspect of EIM&T.

145. Again making reference to the Summary Report for Activity 1, under the heading of Types of EDG Failures, their Causes & Contributory Factors, indicates that all of the 7 bullets giving general guidance for the prevention of recurrence of EDG failures are associated with recommended improvements to EIM&T regimes.

B.3 Electrical, Control & Instrumentation Aspects

B.3.1 Systems and Components Relevant to Safe and Reliable Operation

146. The control systems described to this point comprises three parts, which are typically from different suppliers – the Engine Control Unit (usually by the engine supplier), the AVR (usually by the Alternator supplier) and the genset controller by a specialist company.

B.3.1.1 Automatic Voltage Regulators

147. The alternator Automatic Voltage Regulator (AVR) is typically mounted in a sealed compartment on the alternator non-drive end, with the voltage and current transformers in the termination box at the top of the alternator.

148. The AVR is typically powered from a shaft driven permanent magnet generator, and is a stand-alone controller, that is it regulates the alternator output to nominal voltage. A voltage offset input is provided that allows the genset controller to control system voltage in isolated mode, or the kVARs in infinite bus operation.

B.3.1.2 Genset Controllers

B.3.1.2.1 Specialised Genset Controllers

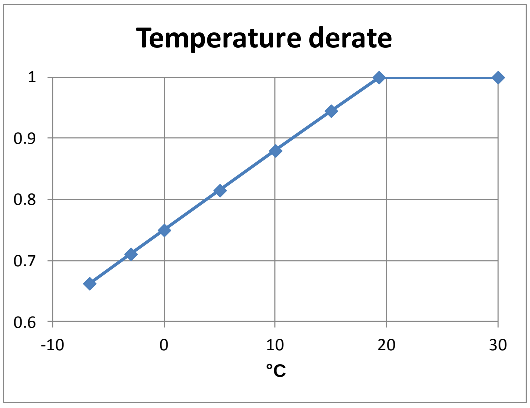
149. Some genset suppliers (Cummins, etc.) can offer both engines and alternators, and they therefore also offer a fully integrated control system with the ECU, AVR and genset controller all implemented on a few highly interconnected circuit boards, with a comprehensive HMI unit allowing every aspect of the genset control to be configured and controlled. The genset controller can provide the following functions:

1) Off, Manual, Automatic or Test modes.
2) Starting and stopping the genset, controlling redundant starter motors, monitoring starter battery voltages, and making multiple start attempts.
3) Control of pre-heating and pre-lubrication.
4) Control of the Neutral Earthing Resistor (NER).
5) The NER should be connected while the genset is operating in Isolated mode, and disconnected while synchronized to the network.
6) Protection functions for the engine and alternator, such as overload, over-current, over/under voltage & frequency, reverse power, phase imbalance, loss of field, winding & bearing over-temperature, and fuel filter blockage.
7) A graphical local HMI interface, and a signals to/from remote HMI's.
8) Additional functional block diagram programming. This simplifies the installation in some instances as a separate PLC is not required.

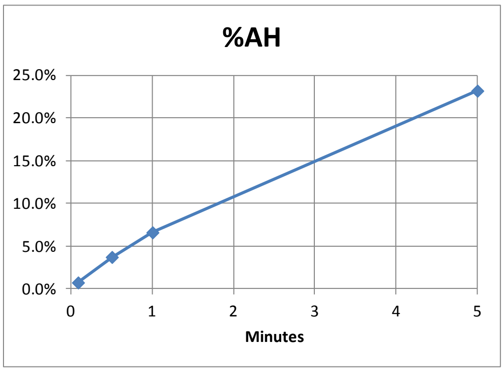
150. The integrated approach has advantages in that there is one HMI and one set of configurations. As all aspects are under the manufacturer's control, the genset controller can be highly optimised. However, a potential disadvantage is that establishing the correct configuration is more opaque as the manufacturer only has to document the controller to the extent needed for his own field engineers. The genset controller specialist suppliers have to document for application engineers, and it is in the supplier's interests to make the documentation clear. Furthermore, the specialist suppliers need to be at the forefront of the technology with good programming software, many communications options for remote access & control, and the ability to interface with many different engines and alternators.

B.3.1.3 Batteries

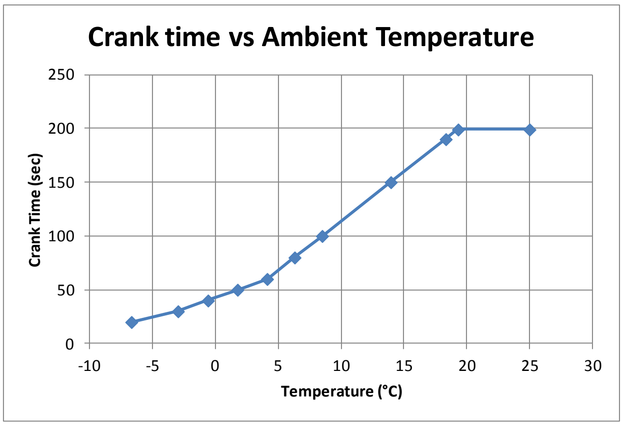
151. A key factor in sizing the batteries is the minimum expected battery temperature: the battery capacity falls as battery temperature falls below room temperature.



152. At 0°, the 1-minute rate battery capacity is typically 75% of nominal for Nickel-Cadmium cells. However, there is a compounding effect: the larger the discharge current in relation to the capacity, the less Amp-hours are available.



153. Therefore, as the temperature falls, the battery capacity falls and there is a further available capacity reduction because the discharge rate is relatively higher. The effect of the temperature and discharge-rate capacity reduction together is graphed below:



B.3.1.3.1 Battery Charging and Conditioning

154. Given the dramatic fall in available cranking time as battery temperature drops, a design decision may be to use a smaller battery and keep the battery environment heated above a minimum temperature.

155. In addition, batteries age as they are chemical devices and the minimum usable capacity is typically 80%. This allowance needs to be taken into account when sizing the battery.

156. Batteries are kept on a floating charge, and every month they are automatically given a boost charge at a higher voltage to equalise the cell voltages.

157. Battery chargers monitor the battery voltage and generate alarms for various conditions that require attention:

1) Charger mains failure
2) Low battery float voltage
3) Low battery voltage
4) High battery voltage

B.3.1.3.2 Battery Technologies

158. The advantages and disadvantages of each battery technology can be observed from the typical parameters tabulated below:

Parameter	Lead-acid	Nickel-Cadmium
Available capacity at high discharge rates	60% at 1 hour rate 28% at 10 minute rate 17% at 5 minute rate	91% at 1 hour rate 40% at 10 minute rate 23% at 5 minute rate
Available capacity at low temperature	70% at 1 minute rate at 0°C	75% at 1 minute rate at 0°C
Charging time	10+ hours	8 hours or less
Charge-discharge cycles	800	2000
Initial cost	Lower	Higher
Life	Tends to be 10 years for high discharge cells, especially if ambient temperatures are high.	Can be 15 years or more.

159. It can be seen that Nickel-Cadmium batteries have a better performance and expected life, but they are more expensive to install.

160. Hence, the choice of battery technology is usually a utility decision, based on their preferences and operating experience.

B.3.1.3.3 Ultracapacitors / Asymmetric Supercapacitors

161. Ultra-capacitors can provide the very high power surges required to start large diesel engines found in heavy duty generator sets. Typically an ultracapacitor operates in conjunction with a conventional lead-acid battery to provide the initial high power surges with the battery providing prolonged power. Key features are:

- Provides initial very high power starting surges.
- Ensures starting of the engine even if the battery is almost discharged.
- Extends the life of the conventional battery.

- Life and performance are largely unaffected by extreme temperatures.
- Allows the use of multi-voltage starting systems.
- Eliminates problematic voltage dip.
- Exhibit very long storage life and are maintenance-free.

162. For starting engines, the ultracapacitor provides higher speed delivery of power during critical break-away phase of starting from 0.5 to 1.5 seconds, where engine static friction and inertial resistance (typically larger for generators that are intermittently run) is overcome and running up to starting speed phase is then achieved.

163. Another major advantage over lead acid batteries is cold weather performance. The ultracapacitor retains 90% of power down to -20ºC compared to typical lead-acid battery which will have lost half its power and so necessitating over-rating or extra heating systems (i.e. extra equipment to reliably operate and maintain). In colder conditions, down to -40ºC, the ultracapacitor still retains 50% of power, maintains availably and reliability and keeps its high current surge benefits, whereas lead-acid is down to 15% capacity and is therefore not capable or dependable for engine starting.

B.3.2 Ageing and Obsolescence

164. The ongoing use of legacy antiquated control equipment has shown to have a negative effect on overall EDG reliability. Outdated EDG equipment has demonstrated several key concerns that limit the availability of EDG power. Legacy EDGs are known to have the following problems:

- Sensor failures (leading to EDG trip).
- Minimal running performance feedback/Lack of visibility of running parameters (e.g. only displayed in the engine room).
- Lack of engine and system diagnostic capabilities.
- Low availability rates.
- Frequent non-starts.
- Increasing occurrence of trips.
- Increasing levels of required ongoing maintenance.
- Non-compliance with modern regulations.
- No resilience to single point/component failures.
- Low-reliability components with obsolescence issues (spares holdings).
- Compounded support problems due to unregulated lifecycle modifications.

B.3.2.1 Life Extensions

165. Units that have been operating for 30 years can be nearing end of life. Therefore a life extension process to develop and install upgraded EDG I&C systems to modernize existing engines and generators is required.

166. The following functional improvements can be gained from a system upgrade and modernisation project:

- Enables continuous engine and system diagnostics.
- Resilience to common-cause or single failures.
- Capabilities to Log status, event, and operator actions.
- Enable remote access from control room and shared operator station.
- Utilise commercially-available components from established, reliable vendors with typical availability guarantees of 20 years.

- Installation and commissioning within EDG outage time periods.
- Renewed (e.g. 30-year) lifetime.
- Provides additional reserve/expansion capacity for future functional expansion.

B.3.2.2 Upgrading to Modern Control Components & Systems

167. Within high-integrity DG industrial applications and industries, it is common to upgrade legacy components and control systems to ensure continued or heightened reliability and availability. Upgrading key generator components and controls systems allows for the following functions and improvements:

- Automatically maintain the EDG in a standby state, ready for an automated start.
- Automatically start and synchronize to electrical bus.
- Provide continuous loaded operation without operator intervention.
- Automatically start and stop upon signals from the plant I&C system, control room, or local operator panel (including pre-starting and post-stopping sequences).
- Automatically refill the fuel day tank, and oil, water and compressed air service tanks.
- Perform continual diagnostics of engine, generator, regulator, and control system, and generate operator alarms and warnings.
- Perform data logging, and periodically transmit extended information packages to operators.
- Provide the ability to test system functionality, protection, and interlocks, using a separate external simulator.

B.3.2.2.1 Typical main requirements of a generator upgrade programme:

- Replace and integrate new elements with the existing engine and generator, without significant mechanical modification.
- Control system to meet requirements for equipment in top-tier safety class.
- Control system to meet Category 1 seismic requirements.
- Control system to meet IEC 61000-4-1, 61000-4-8, 61000-4-9, 61000-4-11-IV-A,6 EMC/EMI standards.
- Updated control systems to have an uptime rate of not less than 99.5%.
- Design lifetime of not less than 30 years.
- Automatic voltage regulator upgraded to a modern design.
- Inclusion of generator protection sub-system.
- Installation and commissioning to be conducted within the period of a refuelling outage (<20 days).
- Pre-commissioning to be conducted within a short timeframe (8-12 days).

B.3.2.3 Advanced ECU Controls

- Advanced ECU control (‘Intelligent Engine Concept’) features for enhanced engine reliability.
- On-line monitoring of individual cylinders to enable:
  - Uniform load distribution among cylinders.
  - Early warning of developing faults and triggering countermeasures.
  - Improved low load operation.

- Active on-line overload protection system to prevent thermal overload.
- Enhanced emission controls: - emission performance characteristics optimised to meet local demands - later updating possible.
- Reduced fuel and lube oil consumption: - engine performance fuel-optimised at 'all' load conditions - 'as new' performance easily maintained over the engine lifetime - mechatronic cylinder lubricator with advanced dosage control.

B.3.2.4 Maintenance and Contract Schedules

B.3.2.4.1 Run-Time Monitoring and Recording

168. Optimisation of run-cycles (frequency and duration) to ensure confidence is maximised in the reliability and operability of the diesel engines whilst minimising premature failures.

B.3.3 EIM&T Best Practices and Main Findings

B.3.3.1 Maintenance

169. Standby generators should typically be serviced every 400 hours or every 6 months, whichever comes first. The Generator Service and Generator Maintenance visits would typically comprise: Visit A – replace oils and filters as well as routine Generator maintenance. Visit B – For routine generator maintenance etc.

B.3.3.2 Testing

B.3.3.2.1 Standard Test Schedules

170. Standard Test Schedules for high reliability generators include:

- Starting test.
- Protection device test.
- Load test.
- Operational temperature checks.
- Speed regulation test.
- Transient Load test.
- Frequency drop.
- Voltage drop.
- Stabilisation time.
- Over-speed test.

171. Temporary or permanent load banks are also required for testing.

B.3.3.3 Generator Set Exercising

172. Exercise the generator set at least once a month for a minimum of 30 min. fully loaded to no less than one-third of the nameplate rating is required.

173. Periods of no-load operation should be held to a minimum because unburned fuel tends to accumulate in the exhaust system.

174. Whenever possible, test the system with actual plant loads in order to exercise the automatic transfer switches and verify performance under real-world conditions.

175. If connecting to the normal load is not convenient for test purposes, the best engine performance and longevity will be obtained by connecting it to a load bank of at least one-third the nameplate rating.

176. It is also necessary as part of the test schedule or maintenance that the final steps are to ensure to return the generator control to AUTO at the conclusion of the tests or maintenance.

B.3.3.4 Testing Starting Batteries

177. Weak or undercharged starting batteries are a common cause of standby power system failures. Even when kept fully charged and maintained, lead-acid starting batteries are subject to deterioration over time and should be replaced approximately every 24 to 36 months — or when they no longer hold a proper charge. NiCad starting batteries require less maintenance than lead-acid and are often used in mission-critical applications. However, they are also subject to deterioration and need to be regularly tested under load.

- Testing batteries: Merely checking the output voltage of the batteries is not indicative of their ability to deliver adequate starting power. As batteries age, their internal resistance to current flow goes up, and the only accurate measure of terminal voltage must be done under load. On some generators, this diagnostic test is performed automatically each time the generator is started. On other generator sets, use a manual battery load tester to verify the condition of each starting battery.
- Cleaning batteries: Keep the batteries clean by wiping them with a damp cloth whenever dirt appears excessive. If corrosion is present around the terminals, remove the battery cables and wash the terminals with a solution of baking soda and water (¼ lb baking soda to 1 quart of water). Be careful to prevent the solution from entering the battery cells, and flush the batteries with clean water when finished. After replacing the connections, coat the terminals with a light application of petroleum jelly.
- Checking specific gravity: In open-cell lead-acid batteries, use a battery hydrometer to check the specific gravity of the electrolyte in each battery cell. A fully charged battery will have a specific gravity of 1.260. Charge the battery if the specific gravity reading is below 1.215.
- Checking electrolyte level: In open-cell lead-acid batteries, check the level of the electrolyte at least every 200 hr of operation. If low, fill the battery cells to the bottom of the filler neck with distilled water.

SECTION C - Effects of Bio-Diesel on the Reliability, Maintainability and Operability of Diesel Engines

C.1. Introduction

178. The reliability, maintainability and operability of emergency diesel generators (EDGs) can be one of the main factors affecting the risk of core damage from a station blackout event. Thus learning from international operational experience of the generic risks associated with the use of bio-diesel in diesel engines, and the specific risks faced by the nuclear industry, can contribute to reducing the probability of station blackout.

179. The fundamental deliverable for this Activity was to be a database of knowledge of the generic risks associated with the use of bio-diesel in diesel engines, and the specific risks faced by the nuclear industry, and including relevant good practice (RGP) with respect to codes, standards and legislation, and an analysis of recommendations for design, installation, operation and maintenance. However when surveying the available literature it became clear that there are a relatively small number of key references on the use of Bio-diesel in diesel engines, and therefore it was concluded that the optimum way forward was to provide simply a report of the study, supported by information from these references.

180. This report of the findings of the study is addressed under the headings of the various sub activities below.

C.2. The Issue

181. In 2009 the Regulatory Support Department of the then SERCO, issued OPEX Advice Note 002/09 (Reference 1) which related the following issue: Diesel for road use in the EU must conform to BS EN 590 which allows up to 5% biodiesel content, a proportion which is set to rise to 7% in the third quarter of this year. Diesel blended with biodiesel is likely to become a requirement for all applications by 1 January 2011. Although biodiesel blends of up to 5% in conventional diesel (so-called ‘B5’) have been available for some time in the UK without reported problems, the US NRC has recently issued a warning of the potential adverse effects of using such fuels in diesel engines used for safety applications (Reference 2). NRC has also noted that ‘B5’ fuels do not need to be labelled as such.

182. Reference 1 further noted that: It is possible that biodiesel is currently being used for applications other than road transport although this is unlikely due to commercial reasons. However, biofuels, and in particular biodiesel, will gradually be introduced for all applications in a relatively short time frame. Diesel engines are common place and they provide power for a range of safety related functions on nuclear plants. Consequently any potential threat to the reliability and performance of this source of power is a cause for immediate concern. It stated that this has a potential to impact on all regulatory intervention plans for sites where diesel engines have a safety related function, and as a regulatory intervention advised Inspectors to secure assurances from licensees that they are aware of this issue and that it is being adequately addressed.

C.3. Relevant Good Practice

183. Reference 3 provides an early Regulatory Guide in respect of fuel-oil systems for standby diesel generators and assurance of adequate fuel-oil quality. It was produced in 1979 by the Office of Standards Development for the US Nuclear Regulatory Commission (NRC).

184. This Regulatory Guide (Reference 3) referred to the requirements for the design of fuel-oil systems for diesel generators that provide standby electrical power for a nuclear power plant that are included in ANSI N 195-1976, ‘Fuel Oil Systems for Standby Diesel-Generators’, which provided a method acceptable to the NRC staff for complying with the pertinent requirements of General Design Criterion 17 of Appendix A to 10 CFR Part 50, subject inter alia, to the following:

- ANSI N 195-1976 does not specifically address quality assurance, and in this regard should be used in conjunction with Regulatory Guide 1.28 'Quality Assurance Program Requirements (Design and Construction)' (Reference 4), which endorses ANSI N45.2-1977 and addresses, 'Quality Assurance Program Requirements for Nuclear Power Plants,' for the design, construction, and maintenance of the fuel-oil system.
- Two methods for the calculation of fuel-oil storage requirements, namely: calculations based on the assumption that the diesel generator operates continuously for 7 days at its rated capacity; and calculations based on the time-dependent loads of the diesel generator. For the time-dependent load method, the minimum required capacity should include the capacity to power the engineered safety features.
- The physical location of storage tanks, relative to the engine, shall be as required by the diesel engine manufacturer.
- Provision for in service inspection and testing in accordance with ASME Section XI, allowing for
- The pressure testing of the fuel-oil system to a pressure 1.10 times the design pressure at 10-year intervals, and a visual examination to be conducted during the pressure test for evidence of component leakages, structural distress, or corrosion.
- Adequate heating should be provided for the fuel-oil system. Use of an oil with a 'cloud point' lower than the 3-hour minimum soak temperature expected at the site during the seasonal periods in which the oil is to be used, and/or by maintenance of the onsite fuel oil above the 'cloud point' temperature.
- Provision of protection against external and internal corrosion.
- Provision of fire protection.
- Provision of a programme to ensure the initial and continuing quality of the fuel oil by regular sampling and physical property testing.
- Accumulated condensate should be removed from storage tanks on a regular basis.
- Storage tanks should be checked for water monthly, as a minimum, and after each operation of the diesel where the period of operation was at least an hour.
- As a minimum, the fuel oil stored in the supply tanks should be removed, the accumulated sediment removed, and the tanks cleaned at 10-year intervals. To preclude the introduction of surfactants in the fuel system, this cleaning should be accomplished using sodium hypochlorite solutions or their equivalent.

185. This Regulatory Guide (Reference 3) was in the process of being updated by the US NRC, and was issued as a Draft Regulatory Guide in July 2012 (Reference 5). It is clear from an initial examination of this draft update that much of the guidance (RGP) provided in Reference 3 remains extant.

C.4. Generic Risks associated with the Use of Bio-Diesel in EDGs

186. The U.S. Department of Energy (Reference 2) has stated that biodiesel blends of B5 or less do not cause noticeable differences in performance compared to No. 2 diesel fuel. However, for the reasons discussed below, B5 blend could be problematical for EDGs and diesel engines that provide functions important to safety.

C.4.1. Cleaning Effect

187. B5 can have a cleaning effect that loosens accumulated sediment in fuel oil storage tanks that previously stored conventional diesel fuel. This sediment can then plug filters and other equipment in the fuel oil system. To prevent the build-up of this sediment, licensees may take the following actions:

- Clean fuel oil storage tanks before putting B5 in them.

- Add and/or upgrade the filters in the fuel oil system.

188. (NRC) Licensees can expect to change and/or clean filters more frequently, especially during the early stages of B5 use.

C.4.2. Water

189. B5 contains suspended particles of water from the manufacturing process. This water will in time fall out of suspension and form “dirty water” in the fuel oil storage tank, which eventually leads to the formation and growth of algae. To prevent the formation of dirty water and the subsequent growth of algae, (NRC) licensees may take the following actions:

- Use a moisture dispersant and biocide in fuel oil storage tanks containing B5.
- Add a fuel/water separator to the fuel oil system.
- Keep fuel oil storage tanks topped off to minimise in-tank condensation.

C.4.3. Biodegradation

190. B5 is biodegradable, and the presence of water, heat, oxygen, and other impurities accelerate the degradation of the fuel supply. To avoid damage caused by fuel degradation, (NRC) licensees may consider not using B5 if it has been stored for an extended period of time (approximately 3 to 6 months or longer).

C.4.4. Material Incompatibility

191. Brass, bronze, copper, lead, tin, and zinc in tanks and fittings may accelerate the oxidation process of B5, creating fuel insoluble or gels and salts. Licensees should avoid using zinc linings, copper pipes and fittings, and brass regulators with B5.

192. (NRC) Licensees should verify that elastomeric materials, such as hoses, gaskets, and O-rings, and their inspection and maintenance, are compatible with B5 and its effects.

C.4.5. Temperature Protection

193. Biodiesel components have higher cloud points (the temperature at which solid particles start to form, or gel) than standard (petroleum) diesel components. The cloud point also varies considerably with the source of the biodiesel component, which is not specified in B5 blends. Clouding may also combine with suspended particles of water and exacerbate adverse cold temperature concerns. Consequently, (NRC) licensees should evaluate and ensure adequate low temperature protection for all diesel generator system components.

C.4.6. Housekeeping

194. Biodiesel is a good solvent. If it is left on a painted surface long enough, it can dissolve certain types of paints. (NRC) Licensees should check for compatibility with paints they use, and should immediately wipe any B5 spills from painted surfaces.

195. Reference 6 relates to the use of bio-diesel fuels in the US Marine Industry. It is interesting to note that it was issued in 2010, the year following NRC Information Notice 2009-02 (Reference 2) which included the above warnings of the potential adverse effects of using such fuels in diesel engines used for safety applications. It is not surprising therefore that Reference 6 refers to some of the same adverse effects. Summarising the main relevant conclusions from Reference 6:

- Safety concerns include inconsistent quality, impact on fuel system components such as engine seals, engine manufacturers’ warranties, disadvantageous hydrophilic properties, cold weather flow drawbacks, and the ability to remain stable long term.

- Bio-diesel fuels contain less energy than petroleum diesel, resulting in a requirement for increased storage capacity.
- There are initial capital costs, such as tank cleaning.
- Bio-diesel fuel has an affinity to absorb moisture and grow bacteria.
- Bio-diesel fuels reduce most emissions relative to high sulphur diesel, but nearly the same results can be achieved by changing to low or ultra-low sulphur.
- Fuel filter and associated maintenance costs are higher for bio-diesel fuel.
- Copper is not compatible with higher blends of bio-diesel.

C.5. Recent Changes in Legislation pertaining to the Use of Diesel/ Bio-Diesel in EDGs

196. In the US, in particular Minnesota, a biofuel use mandate (i.e. a law that requires transportation fuel suppliers and retailers to sell biofuel-blended fuel) was increased from 5% to 10% in July 2014 (Reference 7). The biodiesel (i.e. produced primarily from soybean oil) mandate currently requires a 10% blend of biodiesel (B10) in most diesel sold in Minnesota. The Environmental Protection Agency (EPA) has already approved all the diesel-biodiesel blends. However the B10 mandate is effectively from April through to September, as the level temporarily reverts to B5 from October through to March, due to concerns about B10's performance in cold weather. The law calls for an increase to B20 on 1 May 2018.

197. It is important to note that this US biofuel mandate has a number of exemptions, in particular nuclear plants. Other exemptions are trains; off-road mining and logging equipment; generator manufacturers; Coast Guard boats and certain boats subject to Coast Guard inspection. Number 1 diesel fuel is exempt entirely until 1 May 2020.

198. In the UK, it would appear that the only currently legal biodiesels involve in their manufacture the chemical process of transesterification, by which biodiesels are manufactured as a Fatty Acid Methyl Ester (FAME), using these by products (and others, such as rape seed oil, which uses agricultural land) (References 8,9). The EU Renewable Energy Directive (RED) renewable transport target is 10% biofuel by 2020. However the Renewable Transport Fuel Obligations (Amendment) Order 2011 (RTFO) does not set out a strategy to achieve this. Reference 9 is a European Standard and the associated characteristics, requirements and test methods for FAME were, in 2014, necessary to define the product to be used as automotive diesel fuel and in heating applications.

199. From a European perspective, Cummins Power Generation (Reference 10) details the challenges of FAME biodiesels as fuel, quality, oxidation stability, contamination, microbe growth etc. As a consequence it states that engine manufacturers are sceptical about the use of B100 biodiesel, whereas B5 and B20 are popular depending on the complexity of the engine and the application. However the literature survey has not identified any specific details of recent legislation changes in Europe with respect to the use of biodiesel in EDGs.

C.6. References

1) RSD Briefing Note: Project 567/ACT2/1/PJM/MJN/08/05/09. OpEx Advice Note 002/09 – Biodiesel in Fuel Oil for Diesel Engines. 8 May 2009
2) NRC Information Notice 2009-02. Biodiesel in Fuel Oil could adversely impact Diesel Engine Performance. 23 February 2009
3) US NRC Regulatory Guide 1.137 Fuel Oil Systems for Emergency power Supplies. (Proposed Revision 2 of Regulatory Guide 1.137, dated October 1979). July 2012.
4) Regulatory Guide 1.28 Quality Assurance Program Requirements (Design and Construction)

5) US NRC Draft Regulatory Guide DG-1282 Fuel Oil Systems for Standby Diesel Generators. Revision 1 1979
6) The use of Biodiesel Fuels in the US Marine Industry. Maritime Administration. P Nayyar. April 2010
7) Biofuel Use Mandates – Minnesota House of Representatives. Short Subjects www.house.leg.state.mn.us/hrd/pubs/ss/ss/ssbiofuel. Updated I July 2014
8) Energy and Environment Management – Opinions - Why is this Sustainable Biodiesel Illegal in the UK? David Thorpe 17 December 2011 www.eaem.co.uk/opinions/why-sustainable-biodiesel-illegal-uk
9) BS EN 14214: 2012+A1 January 2014. Liquid Petroleum Products- Fatty Acid Methyl Esters (FAME) for use in Diesel Engines and Heating Applications – Requirements and Test Methods BSI Standards Publication
10) Cummins Power Generation. NRMM Emission Regulations in Europe: What they mean for Diesel Powered Generating Systems. September 2012. White Paper www.power.cummins.com/sites/default/files/literature/technical papers/NAPT-ff22-EN.pdf.

Appendix A.1: Information Sources for Operational Learning and Experience for High-Integrity Industries Reliant on Diesel Generators

Information sources for operational learning and experience for industries with similar reliance/ dependency on diesel generators to the nuclear industry

Ref. ID	Reference Date	Source Reference	Source Reference Title	Topic	Notes
1	Manuscript Completed: February 1996 Date published: September 1999	https://nrcoe.inel.gov/resultsdb/publicdocs/SystemStudies/NUREGCR-5500,%20Vol%205,%20EDG.pdf	Reliability Study: Emergency Diesel Generator Power System, 1987-1993	This report documents an analysis of the reliability of emergency diesel generator (EDG) power systems at U.S. commercial nuclear plants during the period 1987-1993.	
2	2011	http://pbadupws.nrc.gov/docs/ML1125/ML11259A101.pdf	Information Systems Laboratories Emergency Diesel Generators Failure Review 1999 - 2001 Final Report September 14, 2011	This report documents the review of emergency diesel generator (EDG) failures that occurred during the period of January 1, 1999, through December 31, 2001. The failure review identifies a list of common cause categories and provides a table compiled with data covering EDGs failures with brief descriptions impact, corrective actions and relevant comments.	
3	1988	http://adamswebsearch.nrc.gov/webSearch2/view?AccessionNumber=ML003740034	US Nuclear Regulatory Commission Regulatory Guide Office of Nuclear Regulatory Research Regulatory Guide 1.155 Station Blackout August 1988	The reliability of EDGs can be one of the key factors affecting the risk of core damage (due to station blackout event potential). Assuring the high reliability and availability of EDGs at nuclear power plants contributes greatly to reducing the probability of a station blackout event and improving overall nuclear plant safety. Section 1.2 of the Regulatory Guide on station Blackout covers "Reliability Programs" The reliable operation of onsite emergency AC power sources should be ensured by a reliability program designed to maintain and monitor the reliability level of each power source over time for assurance that the selected reliability levels are being achieved. An EDG reliability program would typically be composed of the following elements or activities (or their equivalent): 1. Individual EDG reliability target levels consistent with the plant category and coping duration 2. Surveillance testing and reliability monitoring programs designed to track EDG performance and to support maintenance activities 3. A maintenance program that ensures that the target EDG reliability is being achieved and that provides a capability for failure analysis and root-cause investigations 4. An information and data collection system that services the elements of the reliability program and that monitors achieved EDG reliability levels against target values 5. Identified responsibilities for the major program elements and a management oversight program for reviewing reliability levels being achieved and ensuring that the program is functioning properly.	
4	2007	http://www.nrc.gov/reading-rm/doc-collections/reg-guides/power-reactors/rg/01-009/01-009.pdf	US Nuclear Regulatory Commission Regulatory Guide Office of Nuclear Regulatory Research Regulatory Guide 1.9 Application and Testing of Safety-Related Diesel Generators in Nuclear Power Plants March 2007	This guide provides explicit guidance in the areas of pre-operational testing, periodic testing, reporting and recordkeeping requirements, and valid demands and failures. The preoperational and periodic testing provisions set forth in this guide provide a basis for taking the corrective actions needed to maintain high in-service reliability of installed emergency diesel generators. The database developed will assist ongoing performance monitoring for all emergency diesel generators after installation and during service.	EIM&T
5	current	http://www.dieselforum.org/diesel-at-work/power-generation	Diesel Technology Forum, Diesel at work - Power Generation	Internet forum: Describes how loss of electrical grid power due to storms, natural disasters or high power demands are increasingly common. With a growing dependence on technology and interconnected systems that rely on electricity, power reliability becomes increasingly critical. Hospitals, data centres, water and sewage facilities, fuelling stations, and communication and transportation systems require continuous power to protect public health and safety. Diesel engines provide durable, reliable energy to meet both mobile and stationary power needs. A continuous power supply can mean the difference between life and death. Thanks to diesel-powered generators, supplies of food, water, medicines and fuel can be protected during natural disasters, days of peak grid demand and in remote or isolated locations.	

6	2007	http://www.power-eng.com/articles/print/volume-111/issue-8/departments/dg-update/diesel-generator-failures-lessons-taught-by-hurricanes.html	Diesel Generator Failures: Lessons Taught by Hurricanes David Eoff, Preferred Utilities 08/01/2007	Internet article covering the 2005 hurricane season in the USA causing widespread power outages with many diesel generators called into service. Many generator failures to start occurred with lessons learned from these failures recorded. Understanding the reasons generators failed during the storms of 2005 and applying some of the lessons learned may help ease future emergencies. When diesel generators fail to start, the most common culprits are: • Fuel contaminated by sludge, water or asphaltines • Dead or weak starting batteries • Failed engine-cooling systems.	
7	2013	http://ecmweb.com/ops-amp-maintenance/implementing-standby-generator-maintenance-program-diesel-engines	Electrical Construction and Maintenance Implementing a Standby Generator Maintenance Program for Diesel Engines Oct 16, 2013 David Kovach Electrical Construction and Maintenance	Internet article describing how a well-designed and well-maintained standby power system is the best protection against utility power outages. The top three reasons standby generators fail to automatically start or run are: The generator START switch was left in the OFF position instead of AUTO. • Starting batteries were dead or insufficiently charged. • The fuel filter was clogged due to old or contaminated fuel. All of these common issues can be eliminated with a regular generator maintenance routine performed by properly trained personnel.	
8	2014	http://www.neimagazine.com/features/featurecooling-options-for-emergency-backup-diesel-generators-4159521/	Cooling options for emergency backup diesel generators 14 January 2014 By Nader Ben Said	Internet article which aims to provide a generic comparison of cooling options for diverse stationary diesel generators (water and air cooling) and experience-based recommendations for approaching related new projects.	
9	2013	http://modernsurvivalblog.com/nuclear/nuclear-power-plants-when-the-backups-fail/	Nuclear Power Plants: When The Backups Fail September 24, 2013, by Ken Jorgustin	Internet article questioning what happens if the grid goes down, how long will the backups, such as diesel generators and battery buffers, work and how long before nuclear power plants begin to melt down.	
10	2003	http://www.ncwarn.org/2003/08/	Blackouts leave emergency generators as thin protection at Nuclear plants	Internet article: Following the largest electrical blackout in history which caused sixteen nuclear plants to automatically shut down in the U.S. and Canada, this article questions the reliance of Nuclear Power Plants on Emergency Diesel Generators and highlights the following issues • Nuclear power plants run on offsite power, not their own reactors. • Emergency diesel generators are tested for one hour per year, typically in spring or fall. • Emergency generators are susceptible to overheating. • Testing of emergency generators led to the Chernobyl disaster in 1986. • Emergency diesel generators frequently fail in the U.S. • The NRC regularly allows nuclear plant owners to violate safety regulations	
11	1983	http://www.osti.gov/scitech/biblio/5932679	Reliability of emergency AC power systems at nuclear power plants	This report contains the results of a reliability analysis of the onsite ac power system, and it uses the results of a separate analysis of offsite power systems to calculate the expected frequency of station blackout. Included is a design and operating experience review. Eighteen plants representative of typical onsite ac power systems and ten generic designs were selected to be modelled by fault trees. Operating experience data were collected from the NRC files and from nuclear plant licensee responses to a questionnaire sent out for this project.	
12	2012	http://www5vip.inl.gov/technicalpublications/Documents/5605667.pdf	Online Monitoring Technical Basis and Analysis Framework for Emergency Diesel Generators—Interim Report for FY 2013	This report presents monitoring techniques, fault signatures, and diagnostic and prognostic models for emergency diesel generators.	
13	2012	http://boingboing.net/2012/11/02/in-backup-generators-we-trust.html	In Backup Generators we trust	Internet article claims that "It's normal for backup generators to fail. If we want a more reliable system, we'll have to change the way the grid works." Backup generators aren't 100% reliable. They won't work something like 20%-to-30% of the time. There are solutions that could help keep a hospital up and running in an emergency, even if the emergency power system doesn't work. A micro grid could change that, enabling areas the size of neighbourhoods to operate independently in	

				the event of an emergency.	
14	2012	http://gradworks.umi.com/15/36/1536998.html	Analysis of Emergency Diesel Generators Failure Incidents in Nuclear Power Plants by Hunt, Ronderio LaDavis, M.Eng., HOWARD UNIVERSITY, 2012,	In early years of operation, emergency diesel generators have had a minimal rate of demand failures. As of late, EDGs (emergency diesel generators) have been failing at NPPs (nuclear power plants) around the United States causing either station blackouts or loss of onsite and offsite power. These failures occurred from a specific type called demand failures. This thesis evaluated the current problem that raised concern in the nuclear industry which was averaging 1 EDG demand failure/year in 1997 to having an excessive event of 4 EDG demand failure year which occurred in 2011. To determine the next occurrence of the extreme event and possible cause to an event of such happening, two analyses were conducted, the statistical and root cause analysis. Considering the statistical analysis in which an extreme event probability approach was applied to determine the next occurrence year of an excessive event as well as, the probability of that excessive event occurring. Using the root cause analysis in which the potential causes of the excessive event occurred by evaluating, the EDG manufacturers, aging, policy changes/ maintenance practices and failure components. The root cause analysis investigated the correlation between demand failure data and historical data.	Report would need to be purchased.
15	2009	http://pbadupws.nrc.gov/docs/ML1331/ML13316C047.pdf	Operating Experience Smart Sample (OpESS) FY 2008-01 A negative Trend and Recurring Events Involving Emergency Diesel Generators	The report was in support of the NRC inspector's review of emergency diesel generators (EDGs) problems by giving performance insights and related operating experience (OpE) references. Based on the negative trend information and several EDG issues and concerns, the OpE clearinghouse and NRR management directed development of this Operating Experience Smart Sample (OpESS) to focus inspector attention in this area. NRR staff review of recent operating experience related to EDG failures identified several recurring events and general negative trends	
16	2005	http://pbadupws.nrc.gov/docs/ML0602/ML060200477.pdf	NUREG/CR-6890, Vol. 1 INL/EXT-05-00501, Vol. 1 Re-evaluation of Station Blackout Risk at Nuclear Power Plants Analysis of Loss of Offsite Power Events: 1986-2004	This report is an update of previous reports analysing loss of offsite power (LOOP) events and the associated station blackout (SBO) core damage risk at U.S. commercial nuclear power plants. In addition, a comprehensive review of emergency diesel generator performance was performed to obtain current estimates for the Standardised Plant Analysis Risk (SPAR) models. Overall, SPAR results indicate that core damage frequencies for LOOP and SBO are lower than previous estimates. Improvements in emergency diesel generator performance contribute to this risk reduction.	
17	2003	http://www.nrc.gov/reading-rm/doc-collections/nuregs/contract/cr6819/cr6819v1.pdf	Common-Cause Failure Event Insights: Emergency Diesel Generators (NUREG/CR-6819, INEEL/EXT-99-00613, Volume 1)	This report documents a study performed on the set of common-cause failures (CCF) of emergency diesel generators (EDG) from 1980 to 2000. The data studied was derived from the NRC CCF database, which is based on U.S. commercial nuclear power plant event data. This report presents quantitative presentation of the EDG CCF data and discussion of some engineering aspects of the EDG events.	
18	2011	http://pbadupws.nrc.gov/docs/ML1122/ML11229A183.pdf	ML11229A183 - 0420 - E111: The US Nuclear Regulatory Commission Human Resources Training and Development for Emergency Diesel Generators - Emergency Diesel Generators - Chapter 13 - Case Studies - Lessons Learned and Concerns. September 29, 2011	A presentation from the student reference manual used during nuclear power station standby Emergency Diesel Generator hands-on course presentations to United States Nuclear Regulatory Commission (NRC) management, engineering, and inspection personnel.	
19	2011	http://pbadupws.nrc.gov/docs/ML1122/ML11229A178.pdf	ML11229A178 - 0420 - E111 -The US Nuclear Regulatory Commission Human Resources Training and Development for Emergency Diesel Generators - Chapter 13 - Case Studies - Lessons Learned and Concerns. September 29, 2011	A chapter from the student reference manual used during nuclear power station standby Emergency Diesel Generator hands-on course presentations to United States Nuclear Regulatory Commission (NRC) management, engineering, and inspection personnel.	

20	2013	http://www.neimagazine.com/features/featureemergency-diesel-generators-four-challenges/	Nuclear Engineering International Emergency diesel generators: four challenges 18 October 2013 By Laurent Tessier and Eric Huet	Internet article discussing the need for EDG suppliers to meet increasing customer requirements in a post-Fukushima world, and challenges relating to fuel supply, emissions regulations and control systems.	
21	2013	https://ec.europa.eu/jrc/sites/default/files/summary_report_edgs__online.pdf	European Clearinghouse: Events Related to Emergency Diesel Generators 2013 Summary Report of a European Clearinghouse Topical Study	Summary Report presents the main findings of a study performed by the European Clearinghouse on Operating Experience Feedback of NPPs. The study focuses on analysing specific operating experience related to EDGs at NPPs.	
22	Jan-14	http://nrcoe.inel.gov/resultsdb/publicdocs/CompPerf/edg-2012.pdf	INL/EXT-14-31133 Enhanced Component Performance Study: Emergency Diesel Generators 1998–2012	This report presents an enhanced performance evaluation of emergency diesel generators (EDGs) at U.S. commercial nuclear power plants. The report high lights The increasing trend in the EPS EDG unreliability which was primarily due to the increasing trend in the greater than 1 hour failure to run events. The increasing trend indicates only a small increase in unavailability for the EDG over the last ten years. Decreasing trends were identified in the EDG results for the following: Frequency (events per reactor year) of start demands EPS EDGs. Frequency (events per reactor year) of load and run ≤ 1 hour demands EDGs EPS EDG run hours per reactor year.	
23	1994	http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/26/044/26044983.pdf	Emergency Diesel Generator: Maintenance and Failure Unavailability, and Their Risk Impacts	This report addresses the following topics: a) EDG unavailability due to maintenance during power operation and shutdown, derived from a survey of EDG out-of-service data, b) EDG unavailability due to failure to start and load-run on demand, c) Sensitivity of core-damage frequency (CDF) associated with EDG maintenance unavailability compared to the failure to start and load-run on demand, and d) Relative impact of core-damage frequency of EDG maintenance during power operation versus plant shutdown, and suggestions for consideration in scheduling EDG maintenances.	
24	1987	http://www.osti.gov/scitech/servlets/purl/6237384-vPUica/	Aging of Nuclear Station NUREG/CR-4590 PNL-5832 Vol. 1: Diesel Generators: Evaluation of Operating and Expert Experience	Pacific Northwest laboratory evaluated operational and expert experience pertaining to the aging degradation of diesel generators in nuclear service. The report reviewed diesel-generator experience to identify the systems and components most subject to aging degradation and isolates the major causes of failure that may affect future operational readiness. Evaluations show that as plants age, the percent of aging-related failures increases and failure modes change. A compilation is presented of recommended corrective actions for the failures identified. This study also includes a review of current, relevant industry programs, research, and standards.	
25	2003	http://pbadupws.nrc.gov/docs/ML0317/ML031710318.pdf	NUREG/CR-68 19, Vol. 1 Idaho National Engineering and Environmental Laboratory Common-Cause Failure Event Insights Emergency Diesel Generators	This report documents a study performed on the set of common-cause failures (CCF) of emergency diesel generators (EDG) from 1980 to 2000. The report presents quantitative presentation of the EDG CCF data and discussion of some engineering aspects of the EDG events.	
26	2010	http://www.neimagazine.com/features/featurethe-power-behind-power/	Balance of plant | Emergency backup generators The power behind power 6 October 2010	Internet article describing how Emergency diesel backup generators are vital for safety; every nuclear power reactor having at least two of them. So as new-build begins to take off and the market for replacements heats up, suppliers are gearing up and battling for orders.	
27	2014	http://www.sciencedirect.com/science/article/pii/S0149197014001218	Events related to emergency diesel generators in the nuclear industry: Analysis of lessons learned from the operating experience	This study focuses on specific operating experience related to emergency diesel generators (EDG) at nuclear power plants. The study aims at analysing operating experience for the past twenty years and identifying events that involved failures of EDG or its supporting systems. The selected operating experience was analysed in order to identify type of failures, attributes that contributed to the failure, failure modes, discuss risk relevance, summarise important lessons learned and provide recommendations.	Report would need to be purchased.

28	2000	http://www.oecd-nea.org/nsd/docs/2000/csni-r2000-20.pdf	ICDE Project Report: Collection and Analysis of Common-Cause Failures of Emergency Diesel Generators	This report documents a study performed on the set of common cause failures (CCF) of emergency diesel generators (EDG). The data studied here were derived from the International CCF Data Exchange (ICDE) database, to which several countries have submitted CCF event data. The data span a period from 1982 through 1997.	
29	1995	http://www.techstreet.com/ieee/products/vendor_id/594	IEEE 387-1995 IEEE Standard Criteria for Diesel-Generator Units Applied as Standby Power Supplies for Nuclear Power Generating Stations	This standard describes the criteria for the application and testing of diesel-generator units as Class 1E standby power supplies in nuclear power generating stations.	Report would need to be purchased.
30	2008	http://www.epr-reactor.co.uk/ssmod/liblocal/docs/supporting%20documents/ppc%20application%20-%20diesel%20generators.pdf	Generic information for UK EPR diesel generators	The purpose is to provide relevant information about installations of the UK EPR that could be subject to Pollution Prevention Control (PPC) Regulations 2000. Within the Generic Design Acceptance (GDA) phase, the only Installation identified as being subject to a PPC permit are the diesel generators, as the total thermal input of these combustion plants will exceed 50 MW.	
31	current	http://www.fairbanksmorse.com/bin/151.pdf	Fairbanks Morse generators: setting standards for safety, reliability & quality	On-line Company brochure covering Fairbanks Morse Engine design, manufacture and tests medium speed diesel engine generator sets to comply with Nuclear Regulatory Commission (NRC) requirements. Emergency Diesel Generator (EDG) sets supply electrical power to safely shut down the nuclear reactor in the event of a loss of normal offsite power, coolant accident or other operational anomaly. Typically installed in groups of two or more for redundancy purposes, the EDGs are designed utilising the same stringent requirements as all other safety systems inside the plant.	
32	current	http://www.alstom.com/Global/Power/Resources/Documents/Brochures/emergency-diesel-generators-nuclear-power-plants.pdf?epslanguage=en-GB	Alstom: Emergency Diesel Generators Nuclear Safety First	Company brochure describing Alstom as the global leader in Emergency Diesel Generator (EDG) installation, providing 50% of the world's EDG packages in the last decade. Contains references to these EDG packages in Nuclear Power Plants.	
33	current	http://www.mtuonsiteenergy.com/solutions/nuclear-power-plants/	Website for MTU Onsite Energy, suppliers of Emergency diesel generators for nuclear power plants.	Emergency diesel generators are started when the NPP unit is disconnected from the grid. Emergency diesel generators safeguard the power supply to vital consumers such as the reactor cooling system so that a controlled reactor shutdown can be guaranteed. MTU Onsite Energy has been supplying emergency diesel generators (EDGs) for nuclear power plants for more than 50 years.	
34	current	http://www.mtuonsiteenergy.com/solutions/black-start-diesel-generators/	Website for MTU Onsite Energy, suppliers of Emergency diesel generators to provide a black start capability.	In the event of a blackout, a reliable black start system is essential. Power must be supplied to the gas turbine's starting systems and controls. MTU Onsite Energy black start diesel generator sets (BSDG) provide a fast start-up capability without using auxiliary power.	
35	current	http://www.mtuonsiteenergy.com/solutions/data-centers/	Website for MTU Onsite Energy, suppliers of Emergency diesel generators for data centres.	Data centres need 100% reliability 365 days a year—or they risk data loss and dissatisfied customers, resulting in lost business. MTU Onsite Energy provides highly reliable diesel generator sets with an industry-leading average load factor to assure power supply.	
36		http://www.mtuonsiteenergy.com/fileadmin/fm-dam/mtu_onsite_energy/media-all-site/pdf/en/case-studies/3100501_OE_Diesel_CaseStudy_Synovus_2011.pdf	Standby power is like money in the bank for financial data. Generators back up online banking ATM transactions and other data.	Case study: Synovus, a financial services company, constructed a new mission-critical data centre in Columbus to handle its e-banking, telecom and ATM transactions. It chose emergency standby generator sets from MTU Onsite Energy to prevent any loss of services or data in the event of a utility outage.	
37	current	http://www.mtuonsiteenergy.com/solutions/sewage-water-treatment/	Website for MTU Onsite Energy, suppliers of Emergency diesel generators for sewage and water treatment plants. Includes links to case studies.	Due to the essential nature of sewage and water treatment plants, reliable power is a critical component to maintain 24/7 operations. To support these installations, MTU Onsite Energy offers diesel generator sets covering the complete power range, and featuring industry-leading reliability and availability.	

38		http://www.mtuonsiteenergy.com/fileadmin/fm-dam/mtu_onsite_energy/6_press/case-studies/en/3100341_OE_Diesel_CaseStudy_FairfaxCoWastewater_2010.pdf	Fairfax County upgrades waste water pumping stations with stand-by power with fast response time, easy maintenance improve reliability and efficiency.	case study: When the 30-year-old emergency standby generators at three wastewater pump stations required upgrading, project officials determined it was more cost-efficient to completely replace the units with standby power systems from MTU Onsite Energy than to make the needed upgrades to the existing generators. The new units bring backup power online much faster, and they are more compact, easier to maintain and easier on the environment than their predecessors.	
39	current	http://www.mtuonsiteenergy.com/solutions/healthcare-hospitals/	Website for MTU Onsite Energy, suppliers of Emergency diesel generators for health care facilities.	MTU Onsite Energy provides highly dependable solutions to ensure continuous power supply—from gas-powered cogeneration systems to emergency diesel generator sets.	
40		http://www.mtuonsiteenergy.com/fileadmin/fm-dam/mtu_onsite_energy/media-all-site/pdf/en/case-studies/3082701_OE_Diesel_CaseStudy_Charite_2011.pdf	Emergency power for the Charité - Europe's largest university hospital: Turnkey system ensures hospital services in case of main power grid fail.	Case Study: Since July 2010, two emergency backup gensets supplied by MTU Onsite Energy have been standing by to ensure that the Campus Charité Mitte north section of the Charité University Hospital in Berlin can continue functioning normally even if there is a mains power outage. The generator units are based on MTU type 12V 4000 G23 diesel engines with a combined electrical output of roughly 1,700 kVA and can be up and running inside ten seconds. MTU supplied a turnkey system — as well as the diesel gensets it includes cooling, fuel and exhaust systems, air supply and extraction system and control system.	
41	current	http://www.mtuonsiteenergy.com/solutions/power-stations/	Website for MTU Onsite Energy, suppliers of Emergency diesel generators power stations.	MTU Onsite Energy offers complete solutions to aid a community when a natural disaster or unforeseen long term power outage. occurs, or to supply power in remote locations or for peak demands.	
42		http://www.mtuonsiteenergy.com/fileadmin/fm-dam/mtu_onsite_energy/6_press/case-studies/en/3100281_OE_Diesel_CaseStudy_APREnergy_2010.pdf	APR Energy helps solve Peru's drought caused Hydro-electric power shortage: MTU Onsite Energy Generators offer 60 MW of stand by emergency power.	Case Study: Peru is dependent on numerous hydroelectric generating facilities fed by rivers flowing down from the Andes. Indeed, the country gets upward of 80 percent of its power from this source. However, prolonged drought conditions over the past few years have severely affected the production of hydroelectric power in north-western Peru. Consequently, the country has to find ways to supplement its electricity generation.	
43	2014	http://www.munichre.com/site/hsb/get/documents_E1563157526/hsb/assets.hsb.group/Documents/Knowledge%20Center/447%20%20%20Recommended%20Practice%20for%20Maintaining%20Emergency%20and%20Standby%20Engine-Generator%20Sets.pdf	Hartford Steam Boiler Inspection and Insurance Company Maintaining Emergency and Standby Engine-Generator Sets.	Company on-line brochure Improper or poorly maintained generator sets are more prone to failure and are more likely to fail when needed most. The most common engine failures can be attributed to the starting, cooling, lubrication, or fuel delivery systems. Failure of the electric generator is often attributed to excessive moisture in the generator windings. These types of failures can be minimised or prevented, by implementing regularly scheduled, comprehensive generator maintenance and testing programs. Some units may have heaters to help prevent condensation moisture from developing.	
44		http://powercontinuity.co.uk/diesel-generators/what-are-standby-generators/	Power Continuity: What are standby generators.	Company Website covering the provision of stand-by Generators, often referred to as 'back up generators' or 'emergency power systems'. These Generators are commonly used by hospitals and key government buildings to provide replacement power when the National Grid supply fails.	
45	2006	http://dspace.mit.edu/bitstream/handle/1721.1/35682/76882552-MIT.pdf?sequence=2	Maintenance Practices for Emergency Diesel Generator Engines Onboard United States Navy Los Angeles Class Nuclear Submarines by Matthew Arthur Hawks	All underway US Navy nuclear reactors are operated with diesel generators as a backup power system, able to provide emergency electric power for reactor decay heat removal as well as enough electric power to supply an emergency propulsion mechanism. This thesis examines more than 7,000 maintenance records dated 1989 to 2005 for emergency diesel generator engines onboard Los Angeles class nuclear submarines. As patterns were recognised, high impact items were highlighted and recommendations to reduce risk to operational availability were given.	EIM&T
46	current	http://www.fueltechnologiesinternational.com/	Diesel Generator Fuel Maintenance Systems from Fuel Technologies International (FTI)	Company Website; Fuel Technologies International (FTI) manufactures automated stored diesel fuel maintenance systems and provides comprehensive preventative maintenance programs to fight stored diesel fuel degradation on all fronts—oxidation, microorganism growth, and corrosion—so that your emergency power systems are safe, functional, and stable when you need them most. In an emergency where a loss of power occurs, mission critical facilities (including hospitals, data processing centres, prisons, and banks) are dependent on the operability and reliability of their emergency power systems for safety, security, and	EIM&T

				uninterrupted operation.	
47	current	http://www.cliffordpower.com/stuff/contentmgr/files/0/07a6866e86330788f03dccdd7043dada/misc/is_49_emissions_standby_sets4.pdf	Clifford Power Information sheet: US Environmental Protection Agency (EPA) Emissions Standards for Emergency Standby Diesel Generator Sets	This Information Sheet discusses the regulations for diesel standby sets and generator set systems that qualify. These 'progressive' regulations (called Tier levels) became more stringent over the intervening years and have had a major effect in substantially lowering the levels of nitrogen oxide (NOx), carbon monoxide (CO), particulate matter (PM) and non-methane hydrocarbons (NMHC).	
48	2011	http://www.marineinsight.com/tech/proceduresmaintenance/ways-of-starting-and-testing-emergency-generator/	Internet article: Ways of starting and testing emergency generator	Emergency generator on ship provides power in case the main generators of the ship fails and creates a "dead or blackout condition". According to general requirement, at least two modes of starting an emergency generator should be available. The two modes should be – battery start and hydraulic or pneumatic start. The testing of ship's emergency generator is done every week (as part of weekly checks) by running it unloaded to check if it starts on battery mode. The hydraulic start is done every month to ensure that it is working fine. Also every month automatic start of generator is also done to check its automatic operation and to see whether it comes on load.	
49		http://www.dieselserviceandsupply.com/generators_oil_gas.aspx	Internet article: Diesel Service and Supply	Role of Diesel Power Generators in the Oil & Gas Industry. For the oil and gas industry, power generators are a very important necessity. These generators provide key power sources for the oil and gas industry, particularly to assist with drilling and digging. The procedure of both drilling and digging are key to these industries, and a lot of power is needed to provide service to heavy equipment.	
50	2012	http://www.propublica.org/article/why-do-hospitals-generators-keep-failing	Internet article: Why Do Hospital Generators Keep Failing?	Article discusses examples where power is lost and backup generators don't kick in, leaving critically ill patients without the mechanical help they need to breathe.	
51	2014	http://www.csemag.com/single-article/ensuring-emergency-power-after-a-natural-disaster/9dab6d7c5bdde65503af6cafaf7d28f6.html	Internet article: Ensuring emergency power after a natural disaster. Could a Fukushima-type disaster happen here?	A two page internet article discusses earthquakes, wind, and floods as the forces of nature responsible for challenging the vulnerabilities of emergency and backup power systems. By taking the appropriate precautions these vulnerabilities can be guarded against. Natural disasters are inevitable, and power is likely to be lost in areas hit by disasters. It is important for critical facilities to have standby emergency power to maintain essential services afterward. Fortunately, we can be prepared to weather such extreme events. If we adhere to building code requirements, follow good installation practices, specify certified products, and inspect the installation, we can rest assured that the emergency power will be available to support critical services after the disaster.	
52	current	http://www.wealdpower.com/news/shownews.php?lang=en&id=27	Common Faults and Solutions of Diesel Genets	Weald Power, a professional manufacturer of power generators in China, web page describing faults and recommended corrective action following common faults on a Diesel generator set. Diesel engine cannot start several reasons, if Diesel engine cannot start , look for the causes of diesel engine fuel supply system and compression. Determine the technical state of the engine from the colour of the engine exhaust	
53	2007	http://fuelpurification.com/news	Fuel Purification Systems internet article: Poor Fuel Quality: Cause of Generator Failure	Article discusses the likelihood of poor quality of fuel for the stand-by diesel generators for data centres. It includes a recommendation for a Fuel Tank Maintenance Program for Data Centres Lacking Diesel Fuel Quality Maintenance Systems.	
54		http://www.asne.com/the-importance-of-fuel-maintenance-for-emergency-standby-generators/	Authorised services of new England (ASNE). The Importance of Fuel Maintenance for Emergency Standby Generators	Internet blog describes how a comprehensive standby generator diesel fuel maintenance program will make sure that your fuel is stored, tested and maintained to ensure the highest reliability of the system. It will aid in lowering your carbon footprint by lowering emissions and will also aid in lowering the maintenance costs of your generator's engine.	

55	2001	http://www.neimagazine.com/news/newshuman-error-key-to-taiwan-blackout/	Human error key to Taiwan blackout	Internet report says Maanshan 1 PWR suffered a loss of external power after accumulated salt deposits caused transmission instabilities on incoming power lines. These instabilities caused short circuiting, leading to an electrical fire inside the plant, preventing one diesel generator from picking up the load. The total blackout ensued when the second diesel failed to start. AEC found that personnel abandoned efforts to start the second diesel when it failed to immediately respond. The blackout was ended after two hours when a swing diesel was brought into service. It was later discovered that the second diesel would have been operable. The event left the unit in blackout for two hours, but it had been in hot standby for the previous 21 hours, which minimised the core heat load. AEC confirmed that an auxiliary feed water pump started up, keeping the temperature and pressure in the core decreasing until full power was restored. Shen Li, AEC's director of nuclear regulation, said: 'Had the feed water system failed to function, and had the core temperature and pressure increased or decreased, then this would have been a different story.' The event was said to be the world's first station blackout at a western-designed PWR.	
56	2014	http://www.csemag.com/single-article/comparing-permanent-and-portable-backup-generators/2c5dd3520606f7955efbdd0ea9ec55dd.html	Consulting-Specifying Engineer: Comparing permanent and portable backup generators	Internet article describing how the use of portable generators and manual transfer switches can save business owners time, money, and aggravation. Many of today's business owners are opting to research and invest in their own backup power systems, doing all they can to keep their doors open when disaster strikes and grid power fails. the main consideration is; Should they purchase and install a permanent generator and automatic transfer switch (ATS), which automatically turns on when power goes out? Or should they rent a portable generator and connect it to a manual transfer switch (MTS) when an extended outage occurs or is imminent?	
57	2014	http://www.marineinsight.com/marine/marine-news/headline/10-situations-generator-must-stopped-immediately/	Marine insite: 10 Situations When Ship's Generator Must be Stopped Immediately	The generator onboard, being the powerhouse of the ship, requires regular maintenance and overhauling to ensure efficient and safe operations. Internet article describing the ten cases wherein you must immediately start the standby diesel engine and stop the auxiliary engine in "trouble" before a dangerous situation takes shape of a major disaster: Abnormal/strange sound, Smoke, unusual lubricating parameters, high differential pressure, overspeed, cooling water supply, leakage from piping, vibration and loose parts, non-functional alarms and trips, water in oil.	
58	2010	http://www.marineinsight.com/misc/marine-safety/hydraulic-starting-of-emergency-generator/	Marine insite: Hydraulic Starting of Emergency Generator	Internet article covering emergency generator starting in a marine environment. Maintaining continuous power on the ship is one of the most important tasks while sailing. However, sometimes accidents are inevitable and due to some reason such as breakdown of machinery, technical snag etc. there can be a power failure on the ship. In case of blackout there should be an alternate source of power available and which should come on load automatically. Alternate source of power are taken from batteries and emergency generators to provide power to critical equipment. As batteries cannot provide power for a longer period of time, emergency generators are preferred. One of the most common methods for starting emergency generator is hydraulic starting. Hydraulic system for starting works on the principle of hydraulic and pneumatic, in which, the energy is first stored and then supplied or released for the starting of the engine.	
59	2014	http://www.wealdpower.com/news/shownews.php?lang=en&id=30	The choice of the emergency diesel generators	Fujian Weald Industry Co.Ltd Internet article describing the characteristics of the diesel generators used as emergency diesel generators covering generator capacity, number of generators, type of diesel generator and the control system requirements	
60	2010	https://www.engineereducators.com/docs/EmergencyAndStandbyPowerSystems.pdf	Emergency and Standby Power Systems	Course document to familiarise engineers with emergency and standby combustion diesel engine generator set power system under 600V. Can serve as an introduction to emergency and standby power systems and applications for engineers with little or no professional electrical design experience and also practical application information for more seasoned electrical design professionals.	
61	2016	http://www.nfpa.org/codes-and-standards/document-information-pages?mode=code&code=110	National Fire Protection Association (NFPA) 110: Standard for Emergency and Standby Power Systems	This standard covers performance requirements for emergency and standby power systems providing an alternate source of electrical power in buildings and facilities in the event that the normal electrical power source fails. Systems include power sources, transfer equipment, controls, supervisory equipment, and accessory equipment needed to supply electrical power to the selected circuits. NFPA 110 presents installation, maintenance, operation, and testing requirements as they pertain to the performance of the emergency or standby power supply system (EPSS) up to the load terminals of the transfer switch. Specific topics include definitions of the classification of EPSS; energy sources,	Standard would need to be purchased.

				converters, inverters, and accessories; transfer switches and protection; installation and environmental considerations; and routine maintenance and operational testing.	
62	2014	http://www.nfpa.org/codes-and-standards/document-information-pages?mode=code&code=70	National Fire Protection Association (NFPA) 70: National Electrical Code (NEC) Article 700,	Standard covers the electrical safety of the design, installation and operation and maintenance of emergency systems for illumination and /or power to required facilities when the normal electrical supply or system is interrupted. Chapter 4 Equipment for General Use section 445 contains information on Generators	Standard would need to be purchased.
63	1995	https://standards.ieee.org/findstds/standard/446-1995.html	IEEE Std 446-1995, IEEE Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications	This Recommended Practice addresses the uses, power sources, design, and maintenance of emergency and standby power systems. Chapter 3 is a general discussion of needs for and the configuration of emergency and standby systems. Chapters 4 and 5 deal with selection of power sources. Chapter 6 provides recommendations for protecting both power sources and switching equipment during fault conditions. Chapter 7 provides recommendations for design of system grounding, Chapter 8 provides recommended maintenance practices. Chapter 9 lists the power needs for specific industries. and Chapter 10 provides recommendations for designing to reliability objectives.	Document would need to be purchased.
64	1995	http://standards.ieee.org/findstds/standard/387-1995.html	387-1995 - IEEE Standard Criteria for Diesel-Generator Units Applied as Standby Power Supplies for Nuclear Power Generating Stations	The criteria for the application and testing of diesel-generator units as Class 1E standby power supplies in nuclear power generating stations is described in this IEEE Standard. The principal design criteria, factory production testing, qualification requirements and site testing are covered.	Standard would need to be purchased.
65	2001	http://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&frm=1&source=web&cd=7&ved=0CFoQFjAGahUKEwjYh6b1_KrIAhXC1BoKHQAgBtc&url=http%3A%2F%2Fwww.dtic.mil%2Fcgi-bin%2FGetTRDoc%3FAD%3DADP013484&usg=AFQjCNGNQ_ZAOSJUz-neZqwYS0kFXLnD0Q	Defence Technical Information Centre Compilation Part Notice ADP013484 Failure Modes and Predictive Diagnostics Considerations for Diesel Engines	This paper is part of the following report: New Frontiers in Integrated Diagnostics and Prognostics. Proceedings of the 55th Meeting of the Society for Machinery Failure Prevention Technology. Diesel engines are widely used as generators and prime movers in industry and the military for their durability and efficient performance and they are often used in applications where reliability is a crucial operating requirement. Large and medium size diesel engines can be found in electrical power plants as the prime movers of large oceanic vessels. The purpose of the paper is to present an overview of previous research conducted for diesel engine diagnostics, discuss recent diesel engine diagnostics developments, and to lay the basis for straightforward concept designs for practical diesel engine monitoring/diagnostics systems that will enable system prognostics.	
66		http://www.fnc.co.uk/markets/power-energy/power-generation/investigation-of-bearing-failure-case-study.aspx	Power Generation - Investigation of bearing failure case study	Internet article: Frazer-Nash study to examine the cause of bearing failures on the 825kW diesel generator sets that provide the essential services electricity to a nuclear power station. Using a combination of on-site vibration measurements and root cause analysis, the source of the problem was identified as the clutch, which transmits torque between the diesel engine and the electrical machinery.	
67	2012	http://www.j-mst.org/On_line/admin/files/21-J2010-653_2413-2423_-%EB%B9%8C%EB%8D%94.doc.pdf	Intelligent fault diagnosis method for marine diesel engines using instantaneous angular speed	The normal operation of marine diesel engines ensures the scheduled completion and efficiency of a trip. Any failures may result in significant economic losses and severe accidents. It is therefore crucial to monitor the engine conditions in a reliable and timely manner in order to prevent the malfunctions of the plants. This work describes and evaluates the development and application of an intelligent diagnostic technique.	
68		http://www.aggreko.com/products-and-services/power-generation-rental/generators/	Aggreko Diesel Generator Rental	Company website covers how an Aggreko portable diesel generator can be used as the prime power source for the whole of your installation, or can be set it up as a standby power source so that you can run essential services consistently. The diesel generators support your power supply and add reliability to your grid. They can also be called in as part of a Disaster Recovery Plan, forming an emergency power response and temporary replacement.	

69	2014	http://www.facilitiesnet.com/powercommunication/article/Standby-Generators-Require-Regular-Testing-Maintenance-Exercising-And-Inspection-Facilities-Management-Power-Communication-Feature--14801	Standby Generators Require Regular Testing, Maintenance, Exercising, And Inspection	Internet article: Part 1: Standby Generators Require Regular Testing, Maintenance, Exercising, And Inspection Part 2: Keys To Backup Power System Success: Features, Flexibility, And Redundancy Part 3: Exercise Standby Generators To Keep Them In Fighting Shape Part 4: Preventive Maintenance Is Critical To Dependable Standby Generators For optional or life-safety emergency standby power systems, failure to start or failure to run can have enormous consequences. Regular testing, maintenance, exercising, and inspection can help keep standby generators ready to perform when needed. For optional standby generators (not required by life-safety code), critical loads supported by the generator system typically include data centre and call centre equipment such as UPS systems, cooling, phone systems, and desktop equipment (computers, etc.). For emergency standby generators (required by life-safety code), critical loads supported by the generator system typically include emergency lighting, fire alarm systems, fire pumps, and elevators. Life-safety generators are also sometimes used to additionally support optional loads, such as data centres; however, in this case the life-safety loads take precedence over the optional loads. Good design, quality equipment, trained operating personnel, commissioning, regular inspections and exercising, preventative maintenance, trained service support, and performance testing are all key to reliable performance.	
70	2007	https://www.cumminspower.com/www/literature/technicalpapers/PT-7006-Standby-Katrina-en.pdf	Lessons in emergency power preparedness: Planning in the wake of Katrina	Technical information from Cummins Power Generation Inc. While it is nearly impossible to predict and plan for a complete collapse of a region's infrastructure, there are a number of steps that facility operators can take to minimise standby power system failures to keep the lights and computers running in a small office or a multigenerator power system for a manufacturing plant during future disasters. Generator location – Where a generator set is located often makes a significant difference in whether it functions as designed when disaster strikes. Fuel re-supply – Facility managers should have standing agreements with fuel suppliers that can re-supply fuel during an extended outage. Maintenance – While the storm and floodwaters were the major causes of standby power system failures, poor power system maintenance was also a cause. Dead starting batteries, old diesel fuel and improperly maintained electrical equipment all contributed to power system failures that had little to do with the storm.	
71		http://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&frm=1&source=web&cd=20&ved=0CHEQFjAJOApqFQoTCKygwMTTwcgCFUHCGgodNEwHzQ&url=http%3A%2F%2Fwww.hfs.scot.nhs.uk%2Fpublications%2FSHTN%25205%2520Emergency%2520Electrical%2520Generators.pdf&usg=AFQjCNGUBR64CKcB-vQG3QTKXScP172Bfg	Scottish Hospital Technical Note 5 The Operation and Management of Emergency Electrical Generators in Scottish Healthcare Premises	This Scottish Hospital Technical Note has been prepared to summarise the important issues relating to the operation and management of emergency electrical generator installations within Scottish healthcare premises. An emergency generator installation which fails to perform its required function in the event of disruption to the premises' electrical supply may have serious and potentially life threatening consequences. Effective operational management of emergency electrical services is an essential part of the healthcare facilities.	
72	2014	http://www.fema.gov/media-library-data/1424214818421-60725708b37ee7c1dd72a8fc84a8e498/FEMAP-1019_Final_02-06-2015.pdf	federal Emergency Management Agency: Emergency Power Systems for Critical Facilities: A Best Practices Approach to Improving Reliability	There is a significant likelihood that utility power will not be available for an extended period of time during severe natural hazard events. Thus, it is necessary for critical facilities to have reliable sources of sustained electrical power to achieve continued operation. This document provides guidance on the design and operation of emergency power systems in critical facilities so that they will be able to remain operational for extended periods, as needed.	
73	2013	http://pbadupws.nrc.gov/docs/ML1230/ML12300A122.pdf	U.S. Nuclear Regulatory Commission Regulatory Guide 1.137 Fuel oil systems for Emergency Power Supplies	This regulatory guide (RG) describes updated methods that the staff of the U.S. Nuclear Regulatory Commission (NRC) considers acceptable for use in complying with the NRC requirements regarding fuel oil systems for safety-related diesel powered generators and diesel oil-fuelled gas turbine generators, including assurance of adequate fuel oil quality. The guidance provided may also be applied to the fuel oil systems for non-safety-related standby power supplies to the extent deemed appropriate to the safety significance of the power supplies.	

74	2015	http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002005013	Good Practices for Emergency Diesel Generator System Engineers	The objective of this document is to identify and discuss good practices for EDG system engineers at nuclear power plants. The intent in documenting these practices is: •To provide guidance to plant management and EDG system engineers on productive work activities, information available, training, and responsibilities for either a new EDG system engineer or one who has had these responsibilities for a number of years •To quickly and efficiently transition new engineers into more effective EDG system engineers •To assist utility management in identifying the activities and resources necessary to develop and maintain effective EDG system engineers	
75	2011	http://www.theblaze.com/stories/2011/10/09/calls-to-examine-maintenance-of-nuclear-plants-follow-failure-of-4-emergency-system-generators-in-2011/	Calls to Examine Maintenance of Nuclear Plants Follow Failure of 4 Emergency System Generators in 2011	Internet article: Four generators that power emergency systems at nuclear plants have failed when needed since April, an unusual cluster that has attracted the attention of federal inspectors and could prompt the industry to re-examine its maintenance plans.	

Appendix A.2: Database of Relevant Mechanical Engineering Operational Learning

Incident and Event Reports relevant to Essential Diesel Generators within the nuclear sector

Ref ID	Ref Date	Source Reference	Source Reference Title	Topic	Circumstances Prior to the event	Root Cause and Contributory Factors	Conclusion/Lessons Learned	Severity
1	2012	http://warp.da.ndl.go.jp/info:ndljp/pid/3856371/naiic.go.jp/wp-content/uploads/2012/09/NAIIC_report_lo_res10.pdf	The National Diet of Japan Fukushima Nuclear Accident Independent Investigation Commission	The report catalogues a multitude of errors and wilful negligence that left the Fukushima plant unprepared for the events of March 2011. it examines serious deficiencies in the response to the accident by TEPCO, regulators and the government.	Fukushima Dai chi (Fukushima 1) nuclear power site had 6 Boiling Water Reactor Units. 1, 2 and 3 were operating at power before the event and on detection of the earthquake shut down safely. The 12 on site Emergency Diesel Generators were used to provide the alternating (AC) electrical supplies to power essential post trip cooling.	A massive tsunami caused by the earthquake inundated the site and flooded the Emergency Diesel Generator room. This resulted in the loss of all but one diesel generator, some direct current(DC) supplies and essential instrumentation, and created massive damage around the site leading to the loss of back up cooling. Units 1, 2 and 4 lost all power; Unit 3 lost all AC power, and later lost DC . Unit 5 lost all AC power. The Fukushima Daiichi NPP had some weaknesses which were not fully evaluated by a probabilistic safety assessment. Examples include the lack of protection for the emergency diesel generators, battery rooms and switchgear against flooding and the low likelihood of success of severe accident interventions, given the limited guidance, training and knowledge of plant personnel for severe accident management. Beyond design basis accidents were not sufficiently considered, which affected the capability to maintain cooling of the reactor core, the operators' ability to monitor important safety parameters and the management of the severe accident conditions.	The structure of the Fukushima Daiichi Nuclear Plant was not capable of withstanding the effects of the earthquake and the tsunami. Nor was the Fukushima Daiichi Nuclear Plant prepared to respond to a severe accident. In spite of the fact that TEPCO and the regulators were aware of the risk from such natural disasters, neither had taken steps to put preventive measures in place. It was this lack of preparation that led to the severity of this accident. The regulators and operator were aware of the risk that a total outage of electricity at the Fukushima Daiichi plant might occur if a tsunami were to reach the level o the site. They were also aware of the risk of reactor core damage from the loss of seawater pumps in the case of a tsunami larger than assumed in the Japan Society of Civil Engineers estimation. The operator had not prepared any measures to lessen or eliminate the risk, but failed to provide specific instructions to remedy the situation.	Level 7 ("Severe Accident") by the International Nuclear Event Scale (INES).

2	2012	http://www.wano.info/Documents/Lessons%20Learned.pdf	Institute of Nuclear Power Operations (INPO). Lessons Learned from the Nuclear Accident at the Fukushima Daiichi Nuclear Power Station INPO 11-005 Addendum	The following are considered the most significant operational lessons from the event at the Fukushima Daiichi Nuclear Power Station with regards to emergency diesel generators.	Fukushima Dai chi (Fukushima 1) nuclear power site had 6 Boiling Water Reactor Units. 1, 2 and 3 were operating at power before the event and on detection of the earthquake shut down safely. The 12 on site Emergency Diesel Generators were used to provide the alternating (AC) electrical supplies to power essential post trip cooling.	Following the earthquake, the first of a series of seven tsunamis arrived at the site which exceeded the design basis tsunami height. All AC power for units 1 to 5 was lost when the emergency diesel generators and switchgear rooms were flooded. One air-cooled emergency diesel generator continued to function and supplied electrical power to Unit 6, and later to Unit 5, to maintain cooling to the reactors and spent fuel pools.	Lesson Learned: Plant modifications may be needed to ensure critical safety functions can be maintained during a multi-unit event that involves extended loss of AC power, DC power, and the ultimate heat sink. Plant designs should consider installation of air-cooled emergency diesel generators and cross-connections between units to allow sharing of AC and DC power, fresh- and seawater, and compressed air systems during emergencies. The ability to cross-connect mechanical systems and electrical power between units at Fukushima Daiichi units 5 and 6 and Fukushima Daini greatly improved the operator response following the tsunami.	Level 7 (“Severe Accident”) by the International Nuclear Event Scale (INES).
3							Lesson Learned: Plant design features and operating procedures alone cannot completely mitigate the risk posed by a beyond-design-basis event. Additional preparations must be made to respond if such an event were to occur. Over the years, TEPCO had implemented several changes to improve the ability to mitigate the risks of a core-damaging event. Examples are installing air-cooled diesel generators, modifying the plants to allow cross-connection of electrical buses and cooling water systems, adding fire engines for fire protection, and constructing seismically isolated buildings for use during emergency response. Many of these improvements were vital to the response efforts following the tsunami; however, they were not sufficient to prevent or fully mitigate the consequences of the event.	

4	2011	https://www.edfenergy.com/sites/default/files/jer-srt-stt-pub-fin-001_dnb_stress_test_v1.1.pdf	EU Stress Test - Dungeness B	Station specific responses to the ENREG Stress-Test which required a consideration of 'loss of electrical power', including sequential loss of grid supply and on-site AC generation backup supply leading to a 'station black out' scenario, where all electrical AC supplies are lost.	Following the events at Fukushima Dai chi nuclear power site, EDF Energy completed a series of reviews of systems, processes and procedures across all 8 station sites. The findings from these reviews were incorporated into the Stress Tests.	The Stress Test required a consideration of 'Loss of Electrical Power', including sequential loss of grid supply and on-site AC generation back-up supply leading to a 'Station Black Out' scenario, where all electrical AC supplies are lost. Chapter 1 detailed the electrical arrangements on-site Chapter 5 focused on prevention of severe damage to the reactor and to the irradiated fuel under various loss of electrical power and loss of ultimate heat sink scenarios, including all last resort means and an evaluation of times available to prevent severe damage in various circumstances.	Consideration DNB 5.1: Consideration should be given to enhancing the capability to extend mission times. Conclusion DNB 5.2: In the event of loss of grid, fuel oil supplies are sufficient for diesel generator electrical supplies for up to 48 hours. Conclusion DNB 5.3: At DNB, loss of off-site power combined with loss of the ordinary back-up power supply is an event considered within the safety case and adequate provisions are made to support the essential safety functions. Conclusion DNB 5.4: The current robustness and maintenance of the plant is compliant with its design basis against loss of electrical power. Consideration DNB 5.4: Consider providing supply resilience and recovery actions which would give power supplies for essential control and instrumentation and lighting functions. Conclusion DNB 5.5: A permanently installed on-site system can provide post-trip cooling of a pressurised reactor under a station blackout scenario. Conclusion DNB 5.6: Whilst arrangements exist to provide resilience against some station blackout scenarios, there is currently no explicit station blackout safety case. Conclusion DNB 5.12: The current robustness and maintenance of the plant is compliant with its design basis for loss of electrical power. However, steps to improve the resilience of the plant following a beyond design basis event are being considered.	N/A

5	2011	https://www.edfenergy.com/sites/default/files/jer-srt-stt-pub-fin-004_hra_stress_test_v1.1.pdf	EU Stress Test - Hartlepool	Station specific responses to the ENREG Stress-Test which required a consideration of 'loss of electrical power', including sequential loss of grid supply and on-site AC generation backup supply leading to a 'station black out' scenario, where all electrical AC supplies are lost.	Following the events at Fukushima Dai ichi nuclear power site, EDF Energy completed a series of reviews of systems, processes and procedures across all 8 station sites. The findings from these reviews were incorporated into the Stress Tests.	The Stress Test required a consideration of 'Loss of Electrical Power', including sequential loss of grid supply and on-site AC generation back-up supply leading to a 'Station Black Out' scenario, where all electrical AC supplies are lost. Chapter 1 detailed the electrical arrangements on-site Chapter 5 focused on prevention of severe damage to the reactor and to the irradiated fuel under various loss of electrical power and loss of ultimate heat sink scenarios, including all last resort means and an evaluation of times available to prevent severe damage in various circumstances.	Conclusion HRA 5.1: Loss of off-site power supplies is covered by the existing safety case and the on-site generators will provide diverse supplies. The on-site generators are started via a battery backed system and continue to run supporting their own auxiliaries. There are sufficient supplies of stocks available on-site to allow all post-trip essential safety functions to be met for a number of days. On a best estimate basis and with sensible fuel conservation measures, a 72 hour mission period could be achieved under the current Technical Specifications. Consideration HRA 5.1: Consideration should be given to the practicability of further extending the availability of essential stocks for electrical supplies by either providing additional on-site storage facilities or additional means to replenish stocks to allow an extended operating period. Conclusion HRA 5.2: Loss of off-site power combined with failure of the on-site generators is an event considered within the safety case for an operating reactor and adequate provisions are made to support the essential safety functions. Consideration HRA 5.4: Consideration should be given to reviewing the status of the arrangements to cover the event of Station blackout for Hartlepool.	N/A

6	2011	https://www.edfenergy.com/sites/default/files/jer-srt-stt-pub-fin-002_hnb_stress_test_v1.1.pdf	EU Stress Test - Hunterston B	Station specific responses to the ENREG Stress-Test which required a consideration of 'loss of electrical power', including sequential loss of grid supply and on-site AC generation backup supply leading to a 'station black out' scenario, where all electrical AC supplies are lost.	Following the events at Fukushima Dai ichi nuclear power site, EDF Energy completed a series of reviews of systems, processes and procedures across all 8 station sites. The findings from these reviews were incorporated into the Stress Tests.	The Stress Test required a consideration of 'Loss of Electrical Power', including sequential loss of grid supply and on-site AC generation back-up supply leading to a 'Station Black Out' scenario, where all electrical AC supplies are lost. Chapter 1 detailed the electrical arrangements on-site Chapter 5 focused on prevention of severe damage to the reactor and to the irradiated fuel under various loss of electrical power and loss of ultimate heat sink scenarios, including all last resort means and an evaluation of times available to prevent severe damage in various circumstances.	Conclusion HNB 5.1: Loss of off-site power is an event considered within the Hunterston B safety case and provisions are made to support the essential safety functions for 24 hours. Conclusion HNB 5.2: In the event of loss of grid, there are sufficient supplies of fuel oil for the diesel generators to continue operating under required load for at least a 48 hour mission time. Consideration HNB 5.1: Consideration will be given to the practicability of extending safety case mission times by either providing additional on-site storage facilities or additional diverse means to replenish stocks. Conclusion HNB 5.3: At Hunterston B, loss of off-site power combined with loss of the ordinary back-up AC power supply is an event considered within the safety case and provisions are made to support the essential safety functions. Conclusion HNB 5.4: There are provisions off-site that can be deployed to station in 10 hours that would provide power generation capability and aid in continued post-trip cooling of the reactor. Conclusion HNB 5.5: The current robustness and maintenance of the plant is compliant with its design basis against loss of electrical power. However, steps can be taken to improve the resilience of the plant for a beyond design basis event. Consideration HNB 5.3: Consideration should be given to providing a second dedicated diesel generator for the alternative indication centre.	N/A

7	2011	https://www.edfenergy.com/sites/default/files/jer-srt-stt-pub-fin-003_hpb_stress_test_v1.1.pdf	EU Stress Test - Hinkley Point B	Station specific responses to the ENREG Stress-Test which required a consideration of 'loss of electrical power', including sequential loss of grid supply and on-site AC generation backup supply leading to a 'station black out' scenario, where all electrical AC supplies are lost.	Following the events at Fukushima Dai ichi nuclear power site, EDF Energy completed a series of reviews of systems, processes and procedures across all 8 station sites. The findings from these reviews were incorporated into the Stress Tests.	The Stress Test required a consideration of 'Loss of Electrical Power', including sequential loss of grid supply and on-site AC generation back-up supply leading to a 'Station Black Out' scenario, where all electrical AC supplies are lost. Chapter 1 detailed the electrical arrangements on-site Chapter 5 focused on prevention of severe damage to the reactor and to the irradiated fuel under various loss of electrical power and loss of ultimate heat sink scenarios, including all last resort means and an evaluation of times available to prevent severe damage in various circumstances.	Conclusion HPB 5.1: Loss of off-site power is an event considered within the Hinkley Point B safety case and provisions are made to support the essential safety functions for 24 hours. Conclusion HPB 5.2: In the event of loss of grid, there are sufficient supplies of fuel oil for the gas turbines to continue operating under required load for an extend mission time beyond 24 hours. Consideration HPB 5.1: Consideration should be given to the practicability of extending the availability of essential stocks for electrical supplies, by either providing additional on-site storage facilities or additional means to replenish stocks to allow an extended operating period. Conclusion HPB 5.3: At Hinkley Point B, loss of off-site power combined with loss of the ordinary back-up AC power supply is an event considered within the safety case and provisions are made to support the essential safety functions. Conclusion HPB 5.5: There are provisions off-site that can be deployed to station in 10 hours that would provide power generation capability and aid continued post-trip cooling of the reactor. Conclusion HPB 5.8: The current robustness and maintenance of the plant is compliant with its design basis for loss of electrical power. However, steps to improve the resilience of the plant following a beyond design basis event are being considered.	N/A

8	2011	https://www.edfenergy.com/sites/default/files/jer-srt-stt-pub-fin-005_hya_stress_test_v1.1.pdf	EU Stress Test - Heysham 1	Station specific responses to the ENREG Stress-Test which required a consideration of 'loss of electrical power', including sequential loss of grid supply and on-site AC generation backup supply leading to a 'station black out' scenario, where all electrical AC supplies are lost.	Following the events at Fukushima Dai ichi nuclear power site, EDF Energy completed a series of reviews of systems, processes and procedures across all 8 station sites. The findings from these reviews were incorporated into the Stress Tests.	The Stress Test required a consideration of 'Loss of Electrical Power', including sequential loss of grid supply and on-site AC generation back-up supply leading to a 'Station Black Out' scenario, where all electrical AC supplies are lost. Chapter 1 detailed the electrical arrangements on-site Chapter 5 focused on prevention of severe damage to the reactor and to the irradiated fuel under various loss of electrical power and loss of ultimate heat sink scenarios, including all last resort means and an evaluation of times available to prevent severe damage in various circumstances.	Conclusion HYA 5.1: In the event of loss of off-site power supplies, on-site generators will provide diverse supplies. There are sufficient supplies available on-site to allow all post-trip essential safety functions to be met for a number of days. Conclusion HYA 5.2: Loss of off-site power combined with loss of the ordinary back-up AC power supply is an event considered within the safety case and adequate provisions are made to support the essential safety functions. Consideration HYA 5.2: Consideration will be given to using on-site generators to power the emergency seawater pumps. Consideration HYA 5.4: Consideration should be given to reviewing the status of the arrangements to cover the event of station black out for Heysham 1. Conclusion HYA 5.4: There are provisions off-site that could be deployed to station within 10 hours that could provide power generation capability and aid in continued post-trip cooling of the reactor. Conclusion HYA 5.7 The current robustness and maintenance of the plant is compliant with its design basis for loss of electrical power. However, steps to improve the resilience of the plant following a beyond design basis event are being considered. Consideration HYA 5.7: Consider whether the on-site installation of additional, diverse, permanently installed AC power generators would be appropriate to ensure provision of power to essential systems for an extended mission time, for example 72 hours.	N/A

9	2011	https://www.edfenergy.com/sites/default/files/jer-srt-stt-pub-fin-006_hyb_stress_test_v1.1.pdf	EU Stress Test - Heysham 2	Station specific responses to the ENREG Stress-Test which required a consideration of 'loss of electrical power', including sequential loss of grid supply and on-site AC generation backup supply leading to a 'station black out' scenario, where all electrical AC supplies are lost.	Following the events at Fukushima Dai ichi nuclear power site, EDF Energy completed a series of reviews of systems, processes and procedures across all 8 station sites. The findings from these reviews were incorporated into the Stress Tests.	The Stress Test required a consideration of 'Loss of Electrical Power', including sequential loss of grid supply and on-site AC generation back-up supply leading to a 'Station Black Out' scenario, where all electrical AC supplies are lost. Chapter 1 detailed the electrical arrangements on-site Chapter 5 focused on prevention of severe damage to the reactor and to the irradiated fuel under various loss of electrical power and loss of ultimate heat sink scenarios, including all last resort means and an evaluation of times available to prevent severe damage in various circumstances.	Conclusion HYB 5.1: In the event of loss of grid, there are sufficient supplies of fuel oil for the ordinary backup generators to continue operating under operator controlled load for several days mission time. Conclusion HYB 5.2: In the event of loss of grid, there are sufficient supplies of fuel oil for the diverse backup generators to continue operating under operator controlled load for several days mission time. Consideration HYB 5.1: Consideration should be given to the practicability of extending the availability of essential stocks for electrical supplies, by either providing additional on-site storage facilities or additional means to replenish stocks to allow an extended operating period. Conclusion HYB 5.3: Loss of off-site power combined with loss of the ordinary back-up AC power supply is an event considered within the safety case and adequate provisions are made to support the essential safety functions. Conclusion HYB 5.5: There is currently no safety case explicitly covering Station Black Out (SBO) for Heysham 2. Consideration HYB 5.3: Consideration should be given to reviewing the status of the arrangements to cover the event of Station Black Out (SBO) for Heysham 2. Conclusion HYB 5.6: A no-break DC battery back-up system is provided to supply plant that cannot tolerate the short breaks in power on loss of grid supplies during the Essential Diesel Generator start, run-up and loading time. During Station Black Out (SBO), the backup battery DC supplies are claimed for 30 minutes in the current safety case. The primary concern here is about control and instrumentation.	N/A

10	2011	https://www.edfenergy.com/sites/default/files/jer-srt-stt-pub-fin-008_tor_stress_test_v1.1.pdf	EU Stress Test - Torness	Station specific responses to the ENREG Stress-Test which required a consideration of 'loss of electrical power', including sequential loss of grid supply and on-site AC generation backup supply leading to a 'station black out' scenario, where all electrical AC supplies are lost.	Following the events at Fukushima Dai ichi nuclear power site, EDF Energy completed a series of reviews of systems, processes and procedures across all 8 station sites. The findings from these reviews were incorporated into the Stress Tests.	The Stress Test required a consideration of 'Loss of Electrical Power', including sequential loss of grid supply and on-site AC generation back-up supply leading to a 'Station Black Out' scenario, where all electrical AC supplies are lost. Chapter 1 detailed the electrical arrangements on-site Chapter 5 focused on prevention of severe damage to the reactor and to the irradiated fuel under various loss of electrical power and loss of ultimate heat sink scenarios, including all last resort means and an evaluation of times available to prevent severe damage in various circumstances.	Conclusion TOR 5.1: In the event of loss of grid, there are sufficient supplies of fuel oil for the ordinary back-up generators to continue operating under operator controlled load for a several days mission time. Conclusion TOR 5.2: In the event of loss of grid, there are sufficient supplies of fuel oil for the diverse back-up generators to continue operating under operator controlled load for a several days mission time. Consideration TOR 5.1: Consideration should be given to the practicability of extending the availability of essential stocks by either providing additional on-site storage facilities or additional means to replenish stocks to allow an extended operating period. Conclusion TOR 5.3: Loss of off-site power combined with loss of the ordinary back-up AC power supply is an event considered within the safety case and adequate provisions are made to support the essential safety functions. Conclusion TOR 5.8: There are provisions to deploy equipment to station within an appropriate time frame that would provide power generation capability and aid continued post trip cooling of the reactor.	N/A

11	2011	https://www.edfenergy.com/sites/default/files/jer-srt-stt-pub-fin-007_szb_stress_test_v1.1.pdf	EU Stress Test - Sizewell B	Station specific response to the ENREG Stress-Test which required a consideration of 'loss of electrical power', including sequential loss of grid supply and on-site AC generation backup supply leading to a 'station black out' scenario, where all electrical AC supplies are lost.	Following the events at Fukushima Dai ichi nuclear power site, EDF Energy completed a series of reviews of systems, processes and procedures across all 8 station sites. The findings from these reviews were incorporated into the Stress Tests.	The Stress Test required a consideration of 'Loss of Electrical Power', including sequential loss of grid supply and on-site AC generation back-up supply leading to a 'Station Black Out' scenario, where all electrical AC supplies are lost. Chapter 1 detailed the electrical arrangements on-site Chapter 5 focused on prevention of severe damage to the reactor and to the irradiated fuel under various loss of electrical power and loss of ultimate heat sink scenarios, including all last resort means and an evaluation of times available to prevent severe damage in various circumstances.	Conclusion SZB 5.1: The loss of off-site power is considered within the Sizewell B station safety case. In the event of loss of off-site power, there are sufficient supplies of fuel oil for the diesel generators to continue operating under full load for at least a 72 hour mission time. Conclusion SZB 5.2: The loss of both off-site power and on-site power generation system is considered within the Sizewell B station safety case. There are diverse supplies to recharge batteries via the DC battery charging system and keep them charged for at least 24 hours. Consideration SZB 5.1: Consideration should be given to the practicability of extending the availability of essential stocks by either providing additional on-site storage facilities or additional means to replenish stocks to allow an extended operating period. Conclusion SZB 5.3: In the event of station black out, electrical supplies to essential safety equipment will be maintained by using the DC battery charging system. Consideration SZB 5.2: Consider whether additional means could usefully be installed to extend current battery capacity and supply. Conclusion SZB 5.4: There are provisions off-site that can be deployed to station within hours that would provide power generation capability and aid continued post-trip cooling of the reactor.	N/A
12	2015	https://www.edfenergy.com/sites/default/files/japanese_earthquake_response_programmes_final_report_to_the_onr.pdf	EDF Energy Japanese Earthquake Response Programme ONR Recommendation Closeout Report	This report describes how EDF Energy is enhancing the resilience of its fleet of nuclear power stations to mitigate against extremely unlikely but potentially high impact natural environmental events. This includes enhancements to buildings containing EDGs and associated systems.	Following the events at Fukushima Dai ichi nuclear power site, EDF Energy completed a series of reviews of systems, processes and procedures across all 8 station sites.	Resilience Enhancements work carried out on site has increased the survivability of the on-site infrastructure and supplies, reducing potential dependency on off-site infrastructure.	Specific improvements have been made to flood protection, seismic resilience and other potential hazards to allow Emergency/Essential Diesel Generators backed supplies to support cooling functions following a loss of grid. On-site flood, dam boards have been installed, and above and below ground building penetrations sealed.	N/A

13	2013	http://www.tepco.co.jp/en/nu/fukushima-np/handouts/2013/images/handouts_130723_04-e.pdf	Oil Leakage at Unit 6 Emergency Diesel Generator (B) in Fukushima Daiichi Nuclear Power Station	Oil Leakage Emergency Diesel Generator (B) in Fukushima Daiichi Nuclear Power Station July 2013	During a patrol on Unit 6 emergency diesel generator (B) in a TEPCO operator found that a valve gear oil injection tank was in irregularly high level, and oil was leaking on the floor.	The oil supply valve was opened from the morning on July 22 to 10:30 AM on July 23. It is estimated that the oil overflowed from the valve gear oil injection tank, since lubricant oil was supplied gradually while a priming pump automatically operates for 10 minutes every hour.	Countermeasures put in place; 1. Chain lock will be used to ensure the closing of the supply valve of the valve gear oil injection tank. 2. Fixing tool, which is fixed at the similar valve, will be installed. 3. Chain lock will be used to ensure the closing of the similar valve. 4. A guide will be installed in order to prevent the drain receiving pan from dislocation. 5. Locking management of the door at the D/G Building, etc. will be enhanced.	N/A
14	1980	http://www.nrc.gov/reading-rm/doc-collections/gen-comm/info-notices/1990/in90080.html	Information Notice No. 90-80: Sand intrusion resulting in two diesel generators becoming inoperable	This information notice was intended to alert addressees to the potential damage that may occur to emergency diesel generator (EDG) equipment as the result of the use of abrasive material during maintenance operations. This information notice is based on an event in which sand (aluminium oxide) intruded into the cylinders of two diesel engines at the Susquehanna Steam Electric Station as a result of maintenance related cleaning of the diesel engine intercoolers.	On August 30, 1990, with both Units 1 and 2 operating at 100-percent power, the 'B' EDG at the Susquehanna Steam Electric Station was declared inoperable when plant personnel, performing periodic chemical analysis of EDG lubricating oil samples, found a high concentration of chromium in the 'B' EDG oil samples.	Baroscopic examination of the EDG cylinders revealed significant scoring of numerous cylinder liners and piston rings. The licensee concluded that the source of chromium in the lubricating oil was from the scored cylinder liners. Previously the licensee had found similar scoring of the cylinder liners and piston rings on the 'D' EDG. Further inspection by plant personnel identified the presence of abrasive material (sand) in the intake air manifolds of both the 'B' and 'D' diesel engines.	A root cause analysis concluded that the sand had entered the EDGs during recent maintenance operations involving the cleaning and coating of the inner surface of the tubes in the intercoolers (heat exchangers). These events revealed the vulnerability of the EDGs to damage from foreign material, such as the aluminium oxide particles, which may enter the engine through the combustion air, lubricating oil, fuel oil, or jacket coolant water systems. In addition, these events underscore the importance of implementing strict cleanliness specifications when performing maintenance activities on these subsystems. The application of generally accepted industry practices for maintaining equipment cleanliness levels through the incorporation of cleanliness requirements into maintenance procedures and the training of work crews in the methods for meeting those requirements are considered effective. The fact that the licensee detected the degradation of the cylinder liners as a consequence of required periodic chemical analysis of the lubricating oil is evidence of the value of performing regular lubricating oil analyses.	N/A
15	6	http://www.nrc.gov/reading-rm/doc-collections/gen-comm/info-notices/1983/in83051.html	Information Notice No. 83-51: Recent Engine Failures of Emergency Diesel Generators	This information notice was provided to bring to the attention of licensees and construction permit holders of some events and experience of generic diesel generator problems and corrective action taken	QUAD-CITIES 2, OCTOBER 6, 1982 During the monthly preventive maintenance testing of Unit 2 diesel generator, the diesel tripped on high temperature 10 minutes after loading.	The cause was determined to be fouling in the cooling water heat exchanger. The heat exchanger was replaced and the diesel testing was satisfactorily completed. The licensee placed the heat exchanger on a preventive maintenance schedule for cleaning.	In its continuing review of licensee event reports (LERs), NRC identified during a five month period more than 100 LERs pertaining to diesel generator problems. Most of these appeared to be material, equipment, or component failures . No single common trend was identified. NRC was concerned about the large	N/A

16					SEQUOYAH 2, OCTOBER 20, 1982 During a performance test of diesel generator 2B-B, the cooling jacket circulating water pump on the diesel generator was found to be inoperable as a result of a ball bearing failure in the pump.	The bearing was replaced and the diesel generator was returned to service.	number of diesel generator events. During discussions with diesel manufacturers and licensees, it appeared that many of these events could have been eliminated or prevented by implementation of a conscientious maintenance and inspection program as well as monitoring equipment through a plant's trend program. Some licensees instituted such a program to determine the underlying cause of the failures and to prevent their recurrence. Components or materials that experienced failures were monitored or inspected more frequently. Many affected items were repaired or replaced before actual breakdown. For example, cooling water heat exchangers that were found to be ineffective after a certain period of time because of tube fouling were replaced. Cooling jacket circulating water pump bearings were inspected for wear and replaced in certain intervals. Pressure switches and timers found with drifting set points and were recalibrated or replaced frequently.	N/A
17					SUSQUEHANNA, OCTOBER 27, 1982 During a performance test of a diesel generator, the diesel generator tripped on high vibration.	It was postulated that a vibration switch and a pressure regulator were both involved in the trip. Both were repaired and the diesel generator was returned to service. The equipment will be monitored through the plant's trend program.		N/A
18					BRUNSWICK 1, NOVEMBER 5, 1982 During a quick start testing program of diesel generator No. 4, the diesel generator tripped on "low lube oil pressure."	The same problem occurred 2 days later on the same unit. Both events resulted from intermittent failures of the "low lube oil pressure start time relay" (STR). The relay timed out before actual pressure was above the low trip set point. The relay was replaced and the diesel testing was satisfactorily completed.		N/A
19					DRESDEN 3, NOVEMBER 9, 1982 During a Unit 3 diesel generator surveillance test, the diesel generator tripped on low cooling water pressure.	A defective low cooling water pressure switch caused this event. The switch was replaced and the testing was satisfactorily completed.		N/A
20					RANCHO SECO, MAY 25, 1983 During start up testing, the diesel generator would not reach full operating speed. The Woodward governor speed adjustment on the unit stopped at about 650 rpm.	It was found that the pointer disk was hanging up behind the dial plate. The manufacturer recommended filing about 1/16-inch off the pointer disk to allow free movement.		N/A

21					CALVERT CLIFFS, APRIL 7, 1983 During a routine inspection of the intake air check valve of No. 11 diesel generator, the licensee found a check valve holding pin sheared and the check valve loose. The same valve on two other diesel generators at Calvert Cliffs had been found to be cracked when inspected during 1982. The disk of one of these valves was found broken in two pieces. The engines in question are Fairbanks Morse Model 38TD81/8.	Because these failures did not render the diesel generators inoperable, as evidenced by successful completion of weekly operational tests, no LER was issued. The licensee pointed out that there were internal baffles between the check valves and the diesel turbocharger which made it unlikely to have a piece of the check valve enter the diesel's turbocharger. The check valve in question diverts air between the diesel turbocharger and integral air-blower. Failure of the check valve would result in air being available through the turbocharger at low loads and would affect the load control.		N/A
22					SHOREHAM, OCTOBER 15, 1982; APRIL 15, 1983; APRIL 20, 1983; MAY 4, 1983 During pre-operational testing of Shoreham's three Transamerica Delaval, Inc. emergency diesel generators, the following mechanical problems were identified in the past 9 months and reported by the licensee under 10 CFR 50.55 (e): October 15, 1982 - The jacket water pump shaft failed. April 15, 1983 - The engine head cracked. April 20, 1983 - The fuel injection line failed. May 4, 1983 - The rocker arm bolt failed.	Approximately 2 years before these problems occurred, the licensee discovered the following: 1. Loose hardware in cam gears during initial onsite inspection. 2. Multiple broken cylinder head exhaust bolts resulting from insufficient pipe guide clearances in the exhaust manifold. 3. Cracks in the fuel oil ejector that connects to the fuel oil drip line. 4. Absence of a drilled passageway for the relief valve on one lube oil pump line as required by design. 5. Leaky lube oil cooler tubes resulting from improper rolling in the tube sheet. 6. Cracks in rocker arm push rod socket (or cup). 7. Cam gear fitted bolts not installed at the factory as required. The problems were corrected under the surveillance of vendor representatives.		N/A

23					Louis Allis reported two different potential problems May 1983.	1. At the diesel generator in the Clinton Nuclear Plant, a three-phase rectifier assembly in the exciter was not connected in parallel, which could cause field winding insulation to deteriorate. Louis Allis field service took corrective action by making the necessary connections. 2. Detroit Edison experienced high vibration on its diesel generator. The cause was loose pole wedges. Louis Allis performed a detailed engineering evaluation of this problem and found that in 1976 a material change from HRS 1020 steel to 1045 steel was made. This meant that diesel generators manufactured before this change may experience the same loose pole wedge problem. The affected plants are Fermi, Millstone Unit 2, and Hatch .		N/A

24					TRANSAMERICA DELAVAL - 1981 TO 1983 The manufacturer reported a turbocharger thrust bearing lubrication problem with the following nuclear sites being affected: Shoreham, Perry, WPPSS 4, Grand Gulf, Bellefonte, Midland 1 & 2, Catawba, WPPSS 1, Hartsville, San Onofre, Comanche Peak 1 & 2, Phipps Bend	The design of the lubricating oil system permits the oil flow to the turbocharger bearing only when the diesel generator is running. When the diesel generator is in the standby mode, the turbocharger bearing lube oil system is by-passed to prevent a possible fire hazard should pressurised oil leak around the bearing seals onto hot impellers. Therefore, during start up, a sufficient amount of oil would not be available to adequately lubricate the turbocharger bearing. Because diesels are started once a month and run for a short length of time, premature bearing wear was experienced because of insufficient lubrication. At San Onofre, the wear rate for this condition after 100 hours of operation was equivalent to 15,000 to 20,000 hours of continuous operation. To ensure proper lubrication during start up, a design modification in the form of a lubrication oil drip system causing the lubricating oil to drip on the bearings through an orifice at a given rate was proposed, installed, and tested. An alternate method to this design modification is a change in the operating procedure. Before a monthly start, an operator would manually run the auxiliary lube oil pump for 30 to 60 seconds and confirm lube oil pressure. In the event of an emergency start, the bearings will function until oil pressure is developed.		N/A
25	1985	http://www.nrc.gov/reading-rm/doc-collections/gen-comm/info-notices/1985/in85032.html	Information Notice No. 85-32: Recent Engine Failures of Emergency Diesel Generators	This information notice was provided to alert recipients of potentially significant problems pertaining to engine failures of emergency diesel generators	January 1985, Enrico Fermi Atomic Power Plant Unit 2 Emergency Diesel Generator trip on low lube oil pressure of the number 11.	Subsequent inspection revealed damage to connecting rod bearings and main bearings on the upper crankshaft as well as to some pistons. The other 3 DGs on site were inspected and revealed some of the upper bearings had been damaged on one of the EDG which required the upper bearings to be replaced. The other EDGs showed preliminary signs of wear, but no repairs were necessary. The Fermi engine failure was	In consultation with the engine manufacturer, made the following changes as a result of this problem: 1. Revise surveillance test procedures and Technical Specifications to a. prelube all planned starts b. start engine at idle speed, run for five minutes, and then increase to synchronous speed c. increase load in incremental steps d. on shutdown, decrease load in incremental steps 2. Inspect and replace oil filters and	N/A

						attributed to inadequate lubrication during fast starts.	inspect strainers on a quarterly basis. 3. Conduct bearing inspections (after 20 unplanned starts or after 18 months, whichever comes first) to detect any future problems. 4. Analyse oil samples, including an analysis for metallic on a monthly basis for the next 18 months for trend determination. 5. Perform a spectrographic analysis of lube oil filter media and any deposits that are found during the quarterly replacement.	
26					North Anna Power Station Unit 2, both diesel generators experienced engine failures. December 1984, both diesel generators were inoperable at the same time.	Inspection of the 2J diesel generator engine revealed that upper pistons, numbers 2 and 3, were leaking and the number 11 cylinder liner seal was leaking. The upper pistons, numbers 2, 3, and 11, and cylinder liner number 11 were replaced. The 2H diesel generator engine was found to have shattered rings on the number 10 lower piston. The number 10 lower piston and rings were replaced.	These engine problems occurred in engines that were far from the end of their normal design lives. While the exact causes of these premature failures have not been determined, it was believed that the testing requirements may have aggravated existing situations. Good operating practices, coupled with careful maintenance and periodic inspections, therefore are important. In addition, it was apparent that minimising stress and wear on the diesel generator engines by testing, in accordance with the manufacturer's recommendations, was essential. As part of Generic Letter measures were proposed to reduce the severity of engine starts and loadings. In responding to the letter, many licensees apparently did not elect to consider changes to fast start and fast loading test requirements. Licensees were invited to reconsider the desirability of reducing the severity of engine starts and loading by proposing changes to the Technical Specifications to accomplish the goals of Generic Letter . Facility owners were also invited to re-evaluate the adequacy of their maintenance, testing, and operating practices for the required engine service and to take steps to monitor wear on key engine parts such	N/A
27					February 1985, North Anna Power Station Unit 1 The jacket water tank for one of the diesel generator engines at was found to be empty. On a second occasion, water leakage in the engine was observed.	Subsequent inspection revealed jacket water in other cylinders and in the engine lube oil, severe scoring of the number 3 cylinder liner and upper piston, seizure of the number 3 upper piston, and three failed upper main bearings. The apparent cause of trouble on the engine was the failure of a jacket water seal, which resulted in loss of lubrication to the number 3 cylinder and engine lube oil dilution of which, in turn, caused bearing damage. There appeared to be a similarity between this failure and the Unit 2 engine failures in December 1984 as well as the Unit 2 engine failure in June 1983. The cause of the water leaks was not determined.		N/A

28					March 1985, North Anna Power Station Unit 2 The 2J engine tripped on high crankcase pressure.	Subsequent inspection revealed that two cylinder liners were leaking coolant; they were replaced. Several upper piston insert assemblies also required replacement parts. The lower pistons of the cylinders with damaged parts were inspected, but no abnormal wear was found.	as bearings.	N/A
29					February 1985, William B. McGuire Nuclear Station A diesel generator engine tripped on low lube oil pressure.	During subsequent testing, excessive engine vibration prompted plant operators to manually trip the diesel. Brass metal was found on the oil screens. Four of eleven main bearings were damaged; all main and connection rod bearings were replaced as a precaution. One piston and the crankshaft were also are replaced because of scoring. Following inspection of the other diesel engine, the licensee replaced all main bearings as a precaution because scoring and close tolerances were noted. It appeared that misalignment of the lower crankcase bed contributed to the damage.		N/A
30	1987	http://www.nrc.gov/reading-rm/doc-collections/gen-comm/info-notices/1987/in87004.html	The U.S. Nuclear Regulatory Commission (NRC) Information Notice No. 87-04: Diesel generator fails test because of failed fuel	This notice was to alert recipients to a potentially significant problem pertaining to long-term storage of fuel for diesel engines for emergency service.	On June 27, 1986, at Arkansas Nuclear One Unit 2 (ANO 2), one of the two emergency diesel generators (EDGs) failed to complete a prescribed 24-hour endurance test because of fuel starvation .	The licensee found the screen element in the Y-strainer between the day tank and the engine severely fouled , restricting flow of fuel to the engine. The licensee cleaned the tank and piping and successfully completed the endurance test. The corresponding strainer for the redundant EDG was found not to be as severely fouled. The redundant EDG successfully performed a 24-hour endurance test after the faulted EDG was made operable. During the evaluation of the event, the licensee determined that the day tank strainers had not been routinely inspected and cleaned because the station procedures did not address this action.	This problem highlights the importance of a carefully structured inspection, sampling, and test program to verify continuing acceptability of the fuel for emergency use.	N/A

31	1991	http://www.nrc.gov/reading-rm/doc-collections/gen-comm/info-notices/1991/in91062.html	The U.S. Nuclear Regulatory Commission (NRC) Information Notice No 91-62: Diesel engine damaged caused by hydraulic lockup resulting from fluid leakage into cylinders	The U.S. Nuclear Regulatory Commission (NRC) issued this information notice to alert addressees to the possibility of severe damage to the emergency diesel generator (EDG) engine caused by hydraulic lockup resulting from fluid which had leaked into cylinders of the diesel engine.	June 1991, during a precautionary check in preparation for a routine surveillance test of a Unit 2 emergency diesel generator (EDG), Southern California Edison, the licensee at the San Onofre Nuclear Generating Station, found several pints of water in an engine cylinder.	This precautionary check allowed the licensee to avert severe engine damage. The licensee immediately stopped the surveillance, declared the EDG inoperable, and initiated a work order to determine the cause. After removing the cylinder module, the licensee found that a small leak path had slowly developed on the head gasket, allowing the jacket cooling water to intrude into the cylinder. The licensee had operated this engine 7 days earlier without difficulty. Apparently, a sufficient amount of fluid had leaked after this previous test to partially fill the cylinder with water.	The licensee determined that if the EDG had been started on this occasion without first being checked for water in the cylinders, the EDG would have been severely damaged by hydraulic lockup of the cylinder. While performing a similar precautionary check in 1987, the licensee discovered a similar condition on a Unit 1 EDG that was caused by a cracked cylinder. Furthermore, an EDG at the Palo Verde Nuclear Generating Station was severely damaged in 1986 because it was started after water leaked into a cylinder through a cracked cylinder wall. EDG vendors had recognised the significance of this hazard and have recommended that their clients first check for fluid in the cylinders before starting the engine if the engine has been shut down and cooled for a prolonged period. The NRC has discussed this problem with experienced diesel engine operators and understands that this is also a common practice in non-nuclear industries.	N/A
32	1991	http://www.nrc.gov/reading-rm/doc-collections/gen-comm/info-notices/1991/in91062.html	Information Notice No. 91-62: Diesel Engine Damage caused by Hydraulic Lockup Resulting from Fluid Leakage into Cylinders	The U.S. Nuclear Regulatory Commission (NRC) is issued this information notice to alert addressees to the possibility of severe damage to the emergency diesel generator (EDG) engine caused by hydraulic lockup resulting from fluid which has leaked into cylinders of the diesel engine.	June 1991, Southern California Edison. During a precautionary check in preparation for a routine surveillance test of a Unit 2 emergency diesel generator (EDG),	The licensee at the San Onofre Nuclear Generating Station, found several pints of water in an engine cylinder. This precautionary check allowed the licensee to avert severe engine damage. The licensee immediately stopped the surveillance, declared the EDG inoperable, and investigated the cause. A small leak path had slowly developed on the head gasket, allowing the jacket cooling water to intrude into the cylinder. The licensee had operated this engine 7 days earlier without difficulty. It was determined that if the EDG had been started on this occasion without first being checked for water in the cylinders, the EDG would have been severely damaged by hydraulic lockup of the cylinder. In 1987, a similar condition was discovered on a Unit 1 EDG, caused by a cracked cylinder. An EDG at the Palo Verde Nuclear Generating Station was severely damaged in 1986 because it was started after water leaked into a cylinder	EDG vendors have recognised the significance of this hazard and have recommended that their clients first check for fluid in the cylinders before starting the engine if the engine has been shut down and cooled for a prolonged period. The NRC discussed this problem with experienced diesel engine operators and understands that this is also a common practice in non-nuclear industries.	N/A

						through a cracked cylinder wall.		
33	1991	http://www.nrc.gov/reading-rm/doc-collections/gen-comm/info-notices/1991/in91046.html	Information Notice No. 91-46: Degradation of Emergency Diesel Generator Fuel Oil Delivery Systems July 1991	This information notice was intended to alert addressees to potential inoperability of multiple emergency diesel generators (EDGs) resulting from common cause degradations 1. Inappropriate painting of fuel injection assemblies	McGuire Unit 1: June 1990, the unit was operating at full power	The licensee, Duke Power, declared two EDGs inoperable. This occurred on discovery that paint had been inappropriately sprayed on the exciter commutator rings and on the back side of the fuel rack pivot points. This condition prevented the EDG output from attaining the TS-required 4160 volts in the allotted time (11 seconds).	The lessons to be learned from the inappropriate painting incidents are self-evident. Paint ingress into safety-related equipment including EDGs will affect operability, alter the characteristics and functionality.	N/A
34					Palo Verde Unit 3: March 1990, the unit was operating at full power,	The licensee, Arizona Public Service, discovered paint in the ports for the EDG fuel pump fuel oil metering rods. This made the EDG inoperable, because the paint would most likely have prevented operation of the fuel oil injection system.		N/A
35					Byron Unit 1: March 1989, the unit was operating at 80 percent of full power.	The licensee, Commonwealth Edison, discovered that an EDG failed to start during the monthly surveillance test. Inappropriately applied paint was binding the fuel oil metering rods and thus preventing the EDG from getting enough fuel oil to start.		N/A
36				2. Fouling of fuel oil filters or strainers	Dresden Unit 2: December 1988, the unit was shut down, with all the reactor fuel removed from the reactor vessel, and with both reactor protection system (RPS) buses being powered from one EDG.	The EDG frequency decreased below the set point of the under frequency relays associated with the motor-generator sets. When the relays actuated, the RPS buses were de-energised, resulting in a scram signal on both RPS channels. The standby gas treatment system was automatically initiated and the reactor building ventilation system was automatically isolated. The licensee, Commonwealth Edison, determined the root cause to be a fouled fuel oil filter.	Licensee event reports (LERs) that deal with partially plugged fuel oil filters or strainers show that regular and careful maintenance of these components is important to reliable EDG operation.	N/A
37					Turkey Point Unit 3: On September 1988, the unit was operating at full power	The licensee, Florida Power and Light, declared its B EDG inoperable due to high fuel oil pressure. At the time of the event, Unit 4 was shut down and the A EDG was out of service for maintenance. The licensee determined the root cause to be an excessive interval between fuel oil filter replacements that		N/A

						allowed gradual accumulation of particulate matter in the filter.		
38					Ginna: February 1987, the unit was shut down and with all station electrical power being supplied by the EDGs.	The licensee, Roches-ter Gas and Electric, discovered low fuel oil levels in both day tanks because the fuel oil transfer pump suction strainers were partially plugged. The particulate contamination was analysed as weld flux from plant construction activities and fibrous material from either cleaning rags or filter media. The licensee had to drain and flush the fuel transfer pump suction piping several times to prevent plugging of the strainers when the fuel oil from the storage tanks was recirculated.		N/A
39				3. Potential degradation of fuel oil quality, as measured by licensees' TS	Susquehanna Unit 1: July 1990, both units operating at full power	The licensee, Pennsylvania Power and Light, declared an EDG inoperable because a sample of fuel oil from a storage tank exceeded its TS limit for the concentration of insoluble matter, indicating a loss of stability of the stored fuel oil.	The main concern with degraded EDG fuel oil (particulate contamination) lies in its potential for clogging filters, strainers, and fuel injection equipment through which the fuel oil must flow and thus causing engine failure. All fuel oil tends to degrade in two general ways during extended storage. The first way is oxidation and polymerisation of the fuel oil to yield soluble and insoluble gums. The second way is clustered microbiological growth of bacteria, fungi, or yeasts at the interface of the fuel oil and water present at the bottom of the storage tank. Focusing on the question of degraded fuel oil quality, several standards are used in individual plant Tech Spec requirements for testing EDG fuel oil.	N/A
40					Perry Unit 1: January 1989 , the unit was operating at 70 percent of full power.	The licensee, Cleveland Electric 1 Illumination, declared safety-related equipment inoperable because a sample of fuel oil from a storage tank exceeded its TS limit for the concentration of insoluble matter. The licensee believed the fuel oil aging was accelerated by the addition of new fuel oil a few days before the event.		N/A

41					WNP Unit 2: On January1990, the unit was operating at full power.	The licensee, Washington Public Power Supply, declared all three of its EDGs inoperable, because an EDG fuel oil test of samples drawn on December 27, 1989, indicated that the fuel oil in all three storage tanks did not meet the oxygen accelerated stability criterion, and entered the limiting condition of operation (LCO) . The licensee believes the root cause of this event to be the fuel oil analysis method. The licensee submitted an emergency amendment, which included the substitution of a filter cleanliness test. March 1990, the NRC temporarily approved the amendment. June 4, 1990, the NRC permanently approved a revision of the amendment that included changes in addition to this test substitution.	The standard is intended as a statement of permissible limits of significant fuel properties used for specifying the wide variety of commercially available diesel fuel oils. As such, it most readily applies to determination of the quality of new fuel oil, but does not readily apply to the question of particulate contamination in stored fuel oil.	N/A
42					Diablo Canyon Unit 1: May 1988, while the unit was shut down	The licensee, Pacific Gas and Electric, observed the power output of an EDG to decrease below the licensee's acceptance criterion for a 24-hour load test. The licensee determined that the primary fuel oil filter had become clogged with a fungus growing in the day tank supplying that EDG. The licensee also found fungus and spores in the other day tanks and in the fuel oil storage tanks. The licensee added a biocide and filtered the fuel oil in the day tanks until its acceptance criteria were met for flash point, gravity, viscosity, and particulate contamination		N/A

43	1994	http://www.nrc.gov/reading-rm/doc-collections/gen-comm/info-notices/1994/in94019.html	The U.S. Nuclear Regulatory Commission (NRC) Information Notice No.94-19: Emergency diesel generator vulnerability to failure from cold fuel	This information notice was issued to alert addressees to a safety problem that could lead to the common mode failure of all emergency diesel generator units as a result of temperature-related changes in the fuel oil.	Vermont Yankee During the electrical distribution safety functional inspection 1992	The NRC team found that the emergency diesel generators may be vulnerable to excessive viscosity problems and the formation of wax crystals in cold fuel. The team expressed concern about the operability of the EDGs during those times when the actual outdoor temperature falls below the minimum temperature used in the procurement specification for the pour point of the oil. The inspection team observed no heat tracing on the fuel oil storage tank, located outside, and that the heat tracing on the fuel oil transfer piping was not energised with a safety-related source of power.	Improperly specified (procured) emergency diesel generator fuel oil for which the lowest expected use temperature is not taken into account could lead to a common mode failure of all the emergency diesel generator units.	N/A
					Point Beach During the electrical distribution safety functional inspection	The NRC team found a similar potential vulnerability of emergency diesel generators to excessive viscosity problems in cold fuel oil. A licensee calculation to determine the ability of the fuel oil to drain by gravity from the outside storage tanks to the day tanks indicated that under very low temperatures (-9C [15F]), no drainage would occur because the ambient temperature would be less than the cloud point of the fuel oil in the storage tanks and the above-ground piping.		N/A

44	1996	http://www.nrc.gov/reading-rm/doc-collections/gen-comm/info-notices/1996/in96067.html	The U.S. Nuclear Regulatory Commission (NRC) Information Notice No. 96-67 Vulnerability of emergency diesel generators to fuel oil/lubricating oil incompatibility.	This information notice was issued to alert addressees to a recent finding involving degradation of the power block assembly of two emergency diesel generators caused by an incompatibility of the lubricating oil with fuel oil with a low sulphur content.	December 1995 Preoperational testing of a new safety-related emergency diesel generator (EDG), at the Calvert Cliffs Nuclear Power Plant,	Test engineers for the licensee, Baltimore Gas and Electric Company (BGE), at the Calvert Cliffs Nuclear Power Plant, noted sporadic spikes in crankcase pressure and lubricating oil seeping out from the crankshaft seal. The engine was shut down and BGE conducted a boroscopic inspection of the unit. One cylinder showed indications of abnormal wear. The cylinder liner, piston, and piston rings were removed for analysis and replaced with a spare set. The test program for the safety-related EDG was completed in January 1996. Several days later, during a scheduled 2-year maintenance inspection, BGE found four cylinders with heavy carbon-like deposits on the pistons and behind the piston rings and evidence of abnormal scuffing on the cylinder liners. On further inspection, all the cylinders exhibited some degree of similar degradation, including the replacement cylinder. BGE then inspected a second new EDG that had been installed as a backup power supply in 1995 for station blackout. One cylinder on the station blackout engine exhibited degradation similar to that of the safety-related EDG. Upon disassembly, excessive carbon deposition was found in all cylinders.	BGE assembled a root cause analysis team which concluded that the lubricating oil used was incompatible with low sulphur content fuel. The team found that lubricating oil compatibility depends, in part, on the type of fuel being burned, as the lubricating oil contains an additive package that neutralises the products of combustion, most importantly sulphuric acid, to prevent engine corrosion. After the problem was identified, BGE rebuilt the safety-related EDG and on the basis of the findings, the safety-related EDG was supplied with a different lubricating oil. A series of acceptance tests were then run to validate the root cause. Another characteristic of synthetic lubricating oil was identified during the review of this event. Synthetic oils contain diester additives required to improve solubility of oil additives. In diesel engines with low oil sump temperatures, water may accumulate in the sump because the temperature is too low to vaporise it. This water might cause hydrolysis of the diesters and the resulting acids would react with calcium in the additive to form insoluble compounds (soaps). These compounds may clog filters and degrade performance of a diesel engine.	N/A
45	1997	http://www.nrc.gov/reading-rm/doc-collections/gen-comm/info-notices/1997/in97041.html	The U.S. Nuclear Regulatory Commission (NRC) Information Notice No.97-41: Potentially undersized emergency diesel generator oil coolers	This information notice was issued to alert addressees to the discovery of potentially undersized EDG oil coolers at Limerick Generating Station, Units 1 and 2.	Philadelphia Electric Company (PECO) Nuclear, the licensee for Limerick Generating Station, Units 1 and 2, and its consultant Stone and Webster were evaluating EDG heat exchangers in response to NRC Generic Letter (GL) 89-13.	In the course of this evaluation it was determined that the Limerick EDG lubricating oil coolers were undersized relative to the design conditions reported on the heat exchanger data sheet. The discrepancy between the newly calculated and original design heat transfer surfaces, according to Coltec and its consultants, was caused by a revision in the calculation methodology for designing heat exchangers implemented in 1985.	It therefore appeared that heat exchangers designed before 1985 are smaller in size for the same performance requirements than those designed after 1985. This does not necessarily mean that they are now considered inadequate for meeting the design requirements. PECO Nuclear determined that for the Limerick design, sufficient margin is available given the calculated temperatures of the emergency service water (ESW) system to handle the post-accident loading (which is below the continuous rating).	N/A

46	1998	http://www.nrc.gov/reading-rm/doc-collections/gen-comm/info-notices/1998/in98041.html	The U.S. Nuclear Regulatory Commission (NRC) Information Notice No. 98-41: Spurious shutdown of emergency diesel generators from design oversight	This information notice was issued to alert addressees to recent inspection findings related to a design deficiency that leads to an automatic shutdown of the emergency diesel generator (EDG) when the starting air supply pressure depletes.	November 1989 River Bend Nuclear Station Division 1 EDG tripped within one minute after starting.	The EDG tripped within one minute after starting, as a result of a failed temperature sensor for the No. 7 main bearing. As designed, the sensor bled control air pressure down from 60 psig to 10 psig, and the diesel control logic card, sensing the low pressure, tripped the EDG. The NRC staff questioned the availability of a long term supply of control air. In response, the licensee reviewed procedures and made changes to ensure availability of a long-term air supply.	The problems described emphasise the need for licensees to ensure reliability of systems that perform critical support functions for safety-related systems. In some EDG designs, the starting air system also performs a critical control function that may necessitate ensuring availability of the starting air system throughout the duration of certain analysed events, such as station blackout	N/A
47	1998	http://www.nrc.gov/reading-rm/doc-collections/gen-comm/info-notices/1998/in98043.html	The U.S. Nuclear Regulatory Commission (NRC) Information Notice No. 98-43 Leaks in the emergency diesel generator lubricating oil jacket cooling water jacket piping	This information notice was issued to alert addressees to the potential for leaks in the skid-mounted lubricating oil piping of Fairbanks Morse emergency diesel generators (EDGs) resulting from fatigue failures of welded pipe joints.	Vermont Yankee and Millstone Unit 2 facilities had experienced leaks in the lubricating oil system piping of their Fairbanks Morse EDGs	In 1995, the Vermont Yankee plant experienced a leak on a welded joint in the lubricating oil piping of one of its EDGs. The licensee concluded that the weld crack had initiated from a slag inclusion in the face of this weld and had propagated as a result of engine vibration. Corrective actions included grinding out the slag inclusion (and other weld defects) and rewelding of the joint. In 1997, the plant experienced another leak in a welded joint in the EDG lubricating oil system piping. It was determined that the fatigue cracking was due to a lack of full penetration and a lack in quality of the welds during manufacture. Corrective actions replaced a section of the lubricating oil piping with new piping that conforms to the vendor's latest fabrication requirements, which specify full-penetration welds with additional piping supports to reduce the vibration.	To determine the cause of the cracks at Vermont Yankee, the licensee performed metallurgical examination and destructive load testing of a sample of three partial-penetration welded joints removed from the EDG lubricating oil system. Both axial and bending loads were applied during the tests. The results confirmed that the installed partial penetration welds would withstand loads greater than the yield strength of the piping material and that they had significant strength with respect to the design loads and the ANSI B31.1 Power Piping Code allowable stresses. However, the licensee also concluded that these partial penetration welds were not sufficient to prevent cracks from propagating as a result of vibration-induced fatigue.	N/A

						At Millstone Unit 2, one of the EDGs experienced a through-wall crack in a piping welded joint, which resulted in a lubricating oil leak. The failure was due to vibration-induced fatigue during diesel operation. As a corrective action, the licensee replaced most of vibration-prone piping with new piping. In addition, the welds on all remaining piping were cut out and replaced with full-penetration welds. While preparing for a power upgrade of their Fairbanks Morse EDGs, the Crystal River licensee found partial penetration welds in some of the cooling water system piping. To eliminate the potential of future leaks, the licensee replaced a majority of the skid-mounted piping using full penetration welds.		
48	2007	http://adamswebsearch.nrc.gov/webSearch2/view?AccessionNumber=ML071760544	Nuclear Regulatory Commission Office of Nuclear Reactor Regulation, Washington, DC20555-0001 August 6, 2007 NRC Information notice 2007-27: Recurring events involving Emergency Diesel Generator Operability	The U.S. Nuclear Regulatory Commission (NRC) issued this information notice (IN) to inform addressees of the results of a staff evaluation of recent operating experience to identify recurring events involving the operability of emergency diesel generators (EDGs). The Office of Nuclear Reactor Regulation (NRR) conducted a review of operating experience related to EDG failures that have occurred from the beginning of 2004 and identified the following recurring events and overall tendencies: • Vibration-induced failures of EDG piping and tubing (recurring) • Failure to take prompt corrective action, especially to repair EDG fluid leaks • Inadequate EDG post-maintenance testing	Kewaunee Power Station During an EDG test run, a minor fuel oil leak was identified at a brass fitting located on a copper diesel fuel oil line.	Plant personnel failed to follow the procedural requirements to enter the identified degraded condition into their corrective action program, and no written operability determination or repair was performed. Fifty one days later the EDG had to be secured during a surveillance run when a plant operator noticed that the leak rate had rapidly increased to a point where a pencil-sized stream of fuel oil was observed to be issuing from the original leak location. Approximately three EDG run hours had elapsed between the initial identification of the leak and the time when the leak became more significant.	The licensee's analysis could not prove that the EDG was operable for this 51 day period.	The resulting NRC inspection finding involving corrective action was determined to be of substantial safety significance
49					River Bend Station Unit 1 During EDG testing, a minor leak was identified at a compression fitting in the jacket water cooling system.	A mechanic performed a tightness check on the fitting, but the leakage rate did not change. During a subsequent EDG run, the jacket water tubing separated at the same fitting, causing a significant leak.	The results of an event analysis determined that the EDG was inoperable for approximately 23 days. The most probable cause of the failure was a combination of normal engine vibration and damage caused by over-tightening during past maintenance.	The resulting NRC inspection finding involving corrective action was determined to be of very low safety significance.

50				• Failure to follow procedures. The following are representative examples of the EDG-related events:	Crystal River Unit 3 An EDG output breaker failed to close during a surveillance test.	The breaker closing spring was found not charged with the charging motor control power switch in the "OFF" position.	The licensee's root cause investigation determined that following breaker maintenance, the charging motor control power switch was not verified to be in the "ON" position. The EDG was determined to be inoperable for approximately 28 days.	The resulting NRC inspection finding for exceeding the EDG technical specification allowed outage time was determined to be of very low safety significance
51					Indian Point Nuclear Generating Unit 2 During an extent of condition review for post-maintenance test concerns, the licensee determined that one EDG had not been run at its full load rating following a governor replacement that took place about six months earlier.	During a subsequent full load test, the EDG could not achieve its rated load of 2300 kW.	The licensee determined that the fuel rack linkage was improperly set after the EDG governor replacement.	The resulting NRC inspection finding for inadequate post-maintenance testing was determined to be of very low safety significance
52					Brunswick Steam Electric Plant Unit 1 During a loss of offsite power event Unit 2, a Brunswick Unit 1 EDG experienced a high lubricating oil strainer differential pressure alarm.	The EDG later tripped due to a momentary drop in lube oil header pressure that occurred while plant personnel refilled the cleaned lube oil duplex strainer. The alarm condition was caused by the presence of fibrous lint material in the strainer, the remnants of a cleaning towel that was inadvertently left in the EDG lube oil sump during a previous maintenance activity. It was subsequently learned that the licensee had failed to take effective corrective action after similar high differential pressure alarms were received during two prior post maintenance testing runs.	During the event follow-up it was discovered that the EDG #9 crankshaft bearing was wiped. While the licensee's bearing failure analysis concluded that the exact cause of the failure could not be determined with certainty, the analysis did conclude that the bearing lost effective lubrication and the surface of the bearing was wiped.	The resulting NRC inspection finding for exceeding the EDG technical specification completion time was determined to be of low to moderate safety significance

53	2007	http://www.nrc.gov/reading-rm/doc-collections/gen-comm/info-notices/1989/in89007.html	US Nuclear Regulatory Commission - Office of Nuclear Reactor Regulation Information Notice No. 89-07 Failures of small diameter tubing in control air, fuel oil, and lube oil systems which render emergency diesel generators inoperable.	This information notice was provided to alert addressees to events involving breaks or cracking of small-diameter tubing which can render emergency diesel generators (EDGs) inoperable. Failures apparently caused by vibration had occurred in the tubing of the instrumentation and control air system as well as in the fuel oil and lube oil systems of EDGs. These events had significant safety implications because of the loss of, or the potential loss of, ability of safety-related equipment to perform its intended safety function.	Cooper Nuclear Station During an operability surveillance test of an emergency diesel generator in October 1988, at Cooper Station (Nebraska Public Power District), a loss of control air pressure occurred and the "Turbo Bearing Wear" annunciator alarmed. During engine operation the control air supplies 80 psi air to hold the fuel racks in position. If control air is shut off or if any of the diesel generator trips occur, the 80 psi air flow to the fuel shutoff cylinder is stopped, dumping the fuel racks and tripping the EDG.	After the over speed shutdown relay and the valve associated with maintaining a constant air pressure for the various EDG protective trip mechanisms were rebuilt, the control air pressure still could not be sustained. Subsequently, the licensee identified a circumferential crack in a 1/4-inch stainless steel instrument line during a walk down inspection of the control air system. The cracked line allowed the 30 psi control air to bleed off, reducing pressure on the safety trip valve solenoid which shut down the EDG. Approximately 1 inch of the line was removed and replaced with a compression fitting. The EDG was restarted, and the test was successfully completed.	The cracked piece of stainless steel tubing was sent to a testing laboratory for analysis to determine the cause of the failure. At this time, engine vibration is assumed to be the cause of the failure. The licensee introduced design changes to relocate all engine-mounted instruments subject to high vibration from the engine onto instrument racks.	These events have significant safety implications because of the loss of, or the potential loss of, ability of safety-related equipment to perform its intended safety function. It is expected that recipients will review the information for applicability to their facilities and consider actions, as appropriate, to avoid similar problems.
54					Wolf Creek Generating Station A break in the fuel oil line of an EDG resulted in a fire in November 1988.	A fuel oil leak emanated from a compression fitting on a 1/4-inch surge tank line. The leak quickly increased from a drip to a spray over approximately 45 minutes. Since the leak appeared to be between the nut and the ferrule and was believed to be correctable with the unit in service, and because the EDG was undergoing a 24-hour endurance test, operations personnel did not shut down the EDG. When the attending personnel discovered that the leak had increased significantly, they notified the shift supervisor, and, consequently, the EDG was secured by a control room operator. As the load was reduced, the attending personnel noted flames, reported the fire to control room and security personnel, and actuated the fire alarm. Within about 3 minutes from the time the attending personnel first noticed the fire, the fire was out.	Severe fretting on a horizontal section of the damaged 1/4-inch fuel line was observed when the section was removed for repair. The fretting apparently was caused by vibration-induced rubbing against the larger line to which the fuel line was attached. The broken line also appeared to have been previously broken and repaired in the same place. At that time, the fuel line had been shortened, which could have introduced additional stresses at the location of the new break. A post-event walk down inspection of the EDG revealed further evidence of inadequate support and fretting of other small fluid lines. Previously, similar events indicated that small-diameter tubing installed on EDGs was susceptible to vibration-induced failures which could render the EDGs inoperable. The vibration-induced failures would appear as cracking or breaks as well as holes and wall thinning caused by rubbing of components that contact. These failures are not limited just to specific manufacturers, systems, or materials. The common underlying cause of the failures was the inadequate design or installation of the supports for the small-diameter tubing in a vibration environment.	

55	2009	http://pbadupws.nrc.gov/docs/ML0919/ML091980474.pdf	The U.S. Nuclear Regulatory Commission (NRC) Information Notice No. 2009-14: Painting activities and cleaning agents render emergency diesel generators and other plant equipment inoperable	The U.S. Nuclear Regulatory Commission (NRC) is issuing this information notice (IN) to inform addressees of operating experience in which painting or cleaning activities rendered plant equipment inoperable, particularly a recent event at Comanche Peak in which an emergency diesel generator (EDG) was rendered inoperable.	Comanche Peak Unit 1 November, 2007 The train B EDG failed to start	Failure to start appeared to be paint residue from a small drop of paint on one of the fuel pump metering rods. The location of the paint residue prevented movement of the fuel racks from their normal standby (closed) position in response to a governor demand signal, and the train B EDG was declared inoperable. The lack of movement of the mechanical linkage precluded the admission of sufficient fuel to all of the cylinders, which prevented the engine from starting. The residue was removed and the EDG was successfully started, declared operable, and returned to service.	Licensee corrective actions for this event included the following: • Manipulation of the fuel racks on the other three EDGs manually to determine their condition and to verify that no common-mode failure state existed. Revised the general plant painting procedure to do the following: – Require a post-maintenance “pull test” of the fuel pump control rack mechanisms to ensure that they are free to operate (in addition to visual inspections of the diesel engine area). – Require “as you go” inspection and clean up when painting around sensitive components. – Add an attachment capturing the pictures and information presently contained in the pre-job briefing notebook used by painters. • Included this event in the pre-job briefing for painters to heighten their sensitivity to the problems that paint drops and spatter can cause for mechanical linkages. Had system engineering staff review the information in the painters’ pre-job briefing notebook to ensure that it references all sensitive areas on the EDG that should not be painted.	
56	2015	http://www.dhs.gov/sites/default/files/publications/nppd/ip/daily-report/dhs-daily-report-2015-06-03.pdf	June 1, WSJM 94.9 Benton Harbor – (Michigan) Cook plant Unit 1 taken offline.	Diesel Generator bearing failure.	The Cook nuclear power plant’s Unit 1 was taken offline after a bearing failure occurred in a diesel generator during a routine test.	The bearing failure occurred in a diesel generator during a routine test. Unit 1 will remain out of service for an indefinite amount of time while crews repair the generator. Unit 2 continued to run at full power.	No other information available.	No other information available.

57	2013	https://ec.europa.eu/jrc/sites/default/files/summary_report_edgs__online.pdf	European Clearinghouse: Events Related to Emergency Diesel Generators 2013 Summary Report of a European Clearinghouse Topical Study	Summary Report presents the main findings of a study performed by the European Clearinghouse on Operating Experience Feedback of NPPs. The study focuses on analysing specific operating experience related to EDGs at NPPs.	The selected operating experience was analysed in detail in order to: (i) identify type of failures, attributes that contributed to the failure, failure modes potential or real, affected components, circumstances of failure; (ii) discuss risk relevance; (iii) summarise important lessons learned; and (iv) provide recommendations.	Based on the analysis performed on the selected EDG related events from all the four databases and consequently the lessons learned, recommendations how to tackle the challenging issues were compiled. These recommendations are brought to the attention of regulators, operators, as well as manufacturers. They are grouped into 6 main categories as follows: 1. Preventive maintenance and testing 2. Manufacturing and spare parts 3. Operating Experience Feedback 4. Protective devices [e.g. emergency stop button, low lube oil pressure protection, generator overspeed protection, generator differential overcurrent protection, etc.] 5. Reliability 6. External events	The analysis of almost 700 events confirmed that EDGs have a significant potential to lead to CCF and that tests, inspections and maintenance activities are of paramount importance in order to reduce the risk of EDG failures. The study showed also that in addition to tests, inspections and maintenance, it is necessary to adopt a structured and comprehensive approach to assess risks related to EDG, including the manufacturing stage and the supply of spare parts, the EDG reliability, and the protection against external events, and to update this approach regularly considering the operating experience.	N/A
58	2010	http://www-ns.iaea.org/downloads/ni/irs/irs_guidelines2010.pdf	IRS Guidelines Joint (International Atomic Energy Agency (IAEA)/Nuclear Energy Agency (NEA) International Reporting System for Operating Experience.	Page 26 Degradation of essential support systems	Active safety systems depend on the operability of essential support systems such as AC/DC power (including emergency diesel generator systems and batteries), service water, instrument air and heating, ventilation and air conditioning systems. The dependence on such systems, if inadequately designed or operated, makes active safety systems particularly vulnerable to common mode failures. Weaknesses in design, maintenance and surveillance of such systems may lead to unexpected failures of the safety systems requiring operation of these support systems.	example (a) Several events involved inoperability of multiple emergency diesel generators (EDG) due to degradation of fuel oil delivery system by deterioration of the quality of fuel oil stored at the site.	The event highlighted the surveillance programme implemented at the plants to be insufficient to timely detect the degrading fuel oil quality and the resulting deficiencies in the fuel oil delivery system. In addition, the industry-accepted standards for fuel oil quality did not adequately cover the question of particulate contamination in stored fuel.	
						example (d) While performing a scheduled surveillance test of an emergency diesel generator (EDG), the EDG tripped due to high temperatures in the engine cooling water system. Subsequent investigation revealed water in the instrument air system, which could have resulted in a common mode failure of the redundant EDG, as well as of other safety related components of the plant.	The water intrusion was due to inoperable check valves in an interconnection between the instrument air system and the fire protection system, which had been modified without adequate evaluation of the safety implications. The tests carried out after implementation of the modification were inappropriate to address the problem. A walk down of the entire plant instrument air system was made to ensure that all interconnections to the fire protection system were either isolated or removed.	N/A

59	2000	http://www-ns.iaea.org/downloads/ni/irs/npp-op-ex-96-99.pdf	Nuclear Power Plant Operating Experiences from the IAEA / NEA Incident Reporting System 1996-1999	This report highlights important lessons learned from events reported to the International Reporting System over the period of July 1996-June 1999.	P18 Section 2.5 Experience with diesel generator failure to start. Two failures to start diesel generators with potential safety concern were reported.	There was a failure in a valve in the air start system, and more importantly, there was a failure due to a substitution in the type of diesel fuel used, which could result in the failure of all of the diesels (an example of what is known as common cause failure). In another case, two (of four) diesel generators were found to be unavailable. However, the design basis of the plant was that one diesel alone will allow the plant to be shut down. In addition, the two unavailability's were not related, so this was not a case of common cause failure.	The safety case for the design usually postulates a highly reliable onsite power source. If the high reliability comes into question, then the design adequacy could also come into question. Hence, it is important to monitor trends in emergency power reliability, and to act quickly when the reliability is reduced. The events with common cause failure for all of the diesels are of most concern. An interesting aspect of the event involving the fuel is that the new diesel fuel had been purchased to comply with the low sulphur content requirement set down in national legislation to protect the environment. As it turned out, sulphur reduction also reduced the lubrication process of the diesel fuel, and this ultimately led to the blocking of the fuel injection pump for the diesel engine. The potential for common cause failure for all diesel engines, illustrated here by this event, is always of concern. Also illustrated by this event is the necessity for a comprehensive test and inspection programme and a corrective and preventive maintenance programme.	N/A
60	2010	http://www-ns.iaea.org/downloads/ni/irs/npp-op-ex-05-08.pdf	Nuclear Power Plant Operating Experiences from the IAEA / NEA Incident Reporting System 2005-2008	Common cause vulnerabilities continue to be reported. P17, section 2.4. Experience with common cause	In one event, one of the unit's four EDGs failed to start during its periodic test. The EDGs are needed to power the plant's safety related/critical equipment in case of a loss of power. Each EDG is equipped with two starter motors.	The EDG did not start due to a defective rubber part in one starter motor. Upon inspection, it was discovered that five out of eight starter motors had similar defects. This component was not included in the regular maintenance programme and its safety significance had not been properly recognised. Events involving the EDGs are significant, as the EDGs are safety related/critical components. In one event, a large number of safety related/critical components of the EDG starter motors were found to be defective due to a common cause that had not been identified in the regular maintenance programme. This had the potential to directly impact safe shutdown of the units.	In spite of regular maintenance and periodic testing, some faults can remain undetected. It is important for personnel to have a thorough understanding of the functioning of the plant's equipment in order to assess the safety significance of all the different components. The effects of ageing of these individual components must also be considered.	N/A

61	2006	https://en.wikipedia.org/wiki/Forsmark_Nuclear_Power_Plant#July_2006_incident	Forsmark Nuclear Power Plant	Fosmark 1 July 2006 incident	July 2006, one reactor was shut down after an electrical fault. The first proximal cause of the accident was maintenance work in the adjacent high-voltage yard. An incorrect interlock procedure caused a disconnector to open which sustained an arc that caused a two-phase short circuit in equipment directly adjacent to the plant.	This caused the station generators to disconnect from the grid and, due to the failure of further safety systems this disconnection, in turn, led to a large overvoltage on various supplies within the station. The overvoltage caused failure of the control circuitry of two of the four redundant UPS systems which supplied the safety critical equipment at the plant, including cooling pumps and control circuitry. Though diesel generators started correctly even on these two systems, the lack of control circuitry led to them being unable to engage with their corresponding circuits. The other two UPS systems functioned correctly, surviving the overvoltage, probably due to an undetermined subtle difference in wiring or equipment between the two pairs of units.[	The reactor fully and effectively scrammed immediately on detecting these supply failures. At all times effective cooling was maintained by the pumps operating on the two functioning circuits. Though a number of options remained to operators, had further equipment failed, a single cause (one short-circuit) leading to such a cascade of failures was seen as a challenge to the principle of redundancy and safety in depth.	The incident was rated 2 on the International Nuclear Event Scale. Initially it was rated 1 since two generators remained online. But once it was discovered that all four generators could have failed due to the same fault, the event was upgraded to 2.
62	2006	http://web.archive.org/web/20060907111808/www.foratom.org/content/view/295/341/	Forsmark incident rated as a Level 2	Foratom website: The European Atomic Forum (FORATOM) is the Brussels-based trade association for the nuclear energy industry in Europe. Its main purpose is to promote the use of nuclear energy in Europe by representing the interests of this important and multi-faceted industrial sector.	The incident at the Forsmark nuclear power plant (NPP) in Sweden in July 2006, which led to the precautionary and temporary shutting down of three other nuclear plants in Sweden pending a thorough investigation from the Swedish Nuclear Power Inspectorate (SKI) has, understandably, generated considerable interest in Europe.	The incident was caused by an external electrical fault that triggered a short circuit of the switchgear. Two of the four back-up diesel generators did not start up as expected.	The safety systems required to keep the incident under control – i.e. the automatic shut-down and cooling of the reactor - functioned systematically.	Forsmark incident rated as a Level 2: taken seriously, but "without consequences to people or to the surrounding environment"
63	2001	http://www.aec.gov.tw/webpage/UploadFiles/report_file/1032313985318Eng.pdf	The Station Blackout Incident of the Maanshan NPP unit 1 Atomic Energy Council Taiwan, R.O.C. April 18, 2001 - 1	Soon after the Station Blackout Incident at Maanshan , the Atomic Energy Council (AEC) dispatched both a staff investigation team and independent investigation team to investigate the incident and its impacts. This report summarises the combined observations from both investigation teams.	March 2001, a seasonal sea smog, containing salt deposit, caused the malfunction of all four 345 KV power transmission lines in Fengkang and Hengchun region in southern Taiwan, resulting in the loss of offsite power event at the Maanshan nuclear power plant (NPP).	When the incident happened, the 4.16 KV essential bus B lost all off site power supply. The EDG B automatically started up as designed, but failed to establish excitation to generate voltage. The EDG B automatically started up as designed, but failed to supply AC power. As both the safety-related A/C power systems of unit 1 went out of service and both the emergency diesel generators (EDG) failed to operate, the consequence was a complete loss of power of the two 4.16 KV essential buses at unit.	A "3A" rating of site emergency event on domestic scale was announced subsequently. With the endeavour of plant staff, the essential power was established at by connecting a swing diesel generator to service and the emergency event was thus called off. Neither radioactive release nor environmental impact was observed throughout the whole duration of the incident.	This incident was viewed as the most notable event over the 22-year history of nuclear electricity generation in Taiwan.

64	2001	http://www.neimagazine.com/news/newshuman-error-key-to-taiwan-blackout/	Human error key to Taiwan blackout	Internet report says Maanshan 1 PWR suffered a loss of external power after accumulated salt deposits caused transmission instabilities on incoming power lines.	These instabilities caused short circuiting, leading to an electrical fire inside the plant, preventing one diesel generator from picking up the load. The total blackout ensued when the second diesel failed to start.	AEC found that personnel abandoned efforts to start the second diesel when it failed to immediately respond. The blackout was ended after two hours when a swing diesel was brought into service. It was later discovered that the second diesel would have been operable. The event left the unit in blackout for two hours, but it had been in hot standby for the previous 21 hours, which minimised the core heat load. AEC confirmed that an auxiliary feed water pump started up, keeping the temperature and pressure in the core decreasing until full power was restored.	AEC's director of nuclear regulation, said: 'Had the feed water system failed to function, and had the core temperature and pressure increased or decreased, then this would have been a different story.'	The event was said to be the world's first station blackout at a western-designed PWR.
65	2011	http://www.wano.info/Documents/IG-Report_Nuclear-safety-and-radiation-protection_en%202011.pdf	World Association of Nuclear Operators (WANO): The Inspector General's report on Nuclear Safety and Radiation Protection 2011	Chapter 12.1 EDF SA: premature wear of diesel generator bearings	After the original maker ceased production of the connecting rod big-end bearing shells for the standby diesel generating sets of the 900 MWe series units, another company began producing them in 2002. The diesel engine company responsible for engine supply and maintenance then asked this supplier to manufacture bearing shells identical to the previous ones. October 2010, three of the new generation of bearing shells failed during requalification tests after maintenance on a nuclear plant's last-resort generator diesel engine. In-depth expert appraisal revealed abnormal wear of 8 other bearing shells of the same type.	Prior the end of the in-shop qualification tests, the new generation of bearing shells were fitted at the end of 2009 to 16 sets, previously equipped with the former bearing shells. The French Nuclear Safety Authority (ASN) was kept informed. After the tests, as they were found to have very long service lives, the diesel engine company and EDF announced that the new-type bearing shells were qualified. During a surveillance test on 28 November 2010, serious internal damage was detected in the diesel engine of the standby generator at another nuclear plant. A technical team at the Nuclear Operations Division was assembled in early 2011 and examinations were carried out at other plants possibly affected. These examinations confirmed the presence of premature wear in other bearing shells.	The conclusion was the existence of a potentially generic discrepancy in all the 900 MWe facilities with engines equipped with these bearing shells. Precise characterisation of the physical defect causing the failures led to the corrective action rapidly being determined, involving improved honing of the bearing shells in the factory, increasing the pressure in the lubrication system and changing the oil type. The defective parts were replaced over a three-month period in all the engines affected. In the short term, arrangements were implemented to intensify the monitoring of the behaviour of this equipment in service (more frequent oil analysis) as was an additional maintenance programme. A test engine equipped with the new better-honed bearing shells was subjected to ad hoc endurance tests.	The ASN was immediately informed of the expert appraisal results and a generic significant event in terms of nuclear safety was declared as Level 1 on the International Nuclear Event Scale. However, in one of the 8 plants affected, two of the nuclear units had both standby diesel generators implicated, as well as the plant's last-resort diesel generator. This resulted in the declaration of a Level 2 significant event on the International Nuclear Event Scale.

66	2013	http://www.independent.co.uk/news/uk/home-news/nuclear-scare-at-navy-submarine-base-after-unbelievable-failures-8861361.html	The Independent newspaper - Sunday 06 October 2013 Nuclear scare at Navy submarine base after 'unbelievable' failures	Newspaper article reporting the failure of both the primary and secondary power sources of coolant for nuclear reactors at the Devonport dockyard in Plymouth on 29 July 2012 .	Once a submarine arrives at the Devon base's specially designed Tidal X-Berths, it must be connected to coolant supplies to prevent its nuclear reactor overheating. July 2012 a series of "unidentified defects" triggered the failures which meant that for more than 90 minutes, submarines were left without their main sources of coolant.	A major nuclear incident was narrowly averted at the heart of Britain's Royal Navy submarine fleet. The failure of both the primary and secondary power sources of coolant for nuclear reactors at the Devonport dockyard in Plymouth in July 2012 followed warnings in previous years of just such a situation.	An internal investigation after the incident blamed the complete loss of power on a defect in the central nuclear switchboard. It said the defect had resulted in an "event with potential nuclear implications". Among a number of "areas of concern" uncovered by the investigation was what was described as an "inability to learn from previous incidents and to implement the recommendations from previous event reports". A subsequent review from the Base Nuclear Safety Organisation revealed the "unsuccessful connection of diesel generators" and questioned the "effectiveness of the maintenance methodology and its management", while advising Babcock to "address the shortfalls in their current maintenance regime".	Experts compared the crisis at the naval base, operated by the Ministry of Defence and government engineering contractors Babcock Marine, with the Fukushima Daiichi power-station meltdown in Japan in 2011.
67	2013	http://nuclearinfo.org/article/operational-berths/power-loss-devonport-submarine-base-had-potential-nuclear-implications	Nuclear Information Service: 16 October 2013 Power Loss at Devonport submarine base had 'potential nuclear implications'					
68	2014	http://www.bsee.gov/uploadedFiles/BSEE/Inspection_and_Enforcement/Accidents_and_Incidents/acc_repo/2014/HI%20A%20368A%20Energy%20XXI%2006-AUG-2014.pdf	United States Department of the Interior Bureau of Safety and Environmental Enforcement Gulf of Mexico Region	Accident investigation report for hydrogen explosion	August 2014 at approximately 2:00 am, the main platform generator shut down at Energy XXI's High Island A368 'A' platform, OCS-G-02433.	Upon investigation, the operators observed the main generator belts had severed causing the engine to overheat and shut down due to high temperature. The operators then went to the backup diesel generator and attempted to start the unit. The backup diesel generator utilises two 12 volt direct current (VDC) batteries in series to start the generator's diesel engine. The Lead Operator pushed the start switch on the back up diesel generator and the starter engaged briefly then stopped. The 12 VDC batteries were located side by side in separate battery boxes adjacent to the backup diesel generator. The 'A' Operator removed the cover from the first battery box to check for loose battery post terminal connections and they were secure. The IP then removed the second battery box cover to verify the terminals were secure. When the IP moved the battery terminal connections in battery box #2, it sparked. The sparks from the loose battery terminal connection in battery box #2 are believed to have been the ignition source that caused an accumulation of hydrogen gas in battery box #2 to explode. The	The IP failed to wear Personal Protective Equipment (PPE) to protect face and eyes prior to checking the battery terminal connections on the backup diesel generator. Both operators were in bed when the Main Generator shut down. Fatigue, darkness, and failure to observe surroundings were possible contributing factors.	

						explosion caused battery acid to be blown in the face and eyes of the IP. Sparks from a loose battery terminal connection on the #2 battery for the backup diesel generator are suspected to have ignited a hydrogen gas accumulation in the #2 battery box causing the battery to explode.		
69	2000	https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/373812/SafetyDigest2_2001.pdf	Marine Accident Investigation Branch (MAIB) - Safety Digest 02/2001	CASE 7 Overheated Diesel	November 2000 the motor-driven container vessel Queensland Star, was about to sail from Wellington, New Zealand. During her time in port some repairs had been carried out on the generator fuel cooling system which necessitated the generators to operate on diesel fuel. She sailed with the cooling water systems back in use, the generator fuel system had been switched back to heavy fuel oil.	Three diesel generators were running, and a fourth was on stand-by. The fuel was being supplied through a seastar blender and filters. About 20 minutes after leaving, one of the fuel filters on the blender became blocked. The second filter was brought into the system but this, too, suffered the same fate. With no fuel getting through the blender, the generators showed signs of fuel starvation.	A total loss of electrical power is serious at any time, but in restricted waters, it has the potential to create a major accident. It can result in damage to the vessel, injury, or loss of life to the crew and passengers, and serious environmental damage/ contamination. This accident highlights a number of important points. 1. Fuel starvation: On completion of any maintenance or repair work to an essential system, it is important that the system involved is not only checked initially for correct operation, but is monitored closely over the next few hours. 2. Emergency power Emergency generators are just that they MUST be able to start on demand when everything else fails. Those responsible for them must periodically test the complete emergency system, including any automatic starting arrangements.	N/A
70		https://pure.strath.ac.uk/portal/files/211225/strathprints004990.pdf	An Investigation of Diesel-Generator Shaft and Bearing Failures. by I.A. Craighead* & T.G.F. Gray	A shaft failure in a diesel generator required investigation, especially when similar sets began to show signs of excessive bearing housing wear.	An unexpected shaft failure in a 634 kW set after only 4000 hours of operation (from new) caused concern. This machine was being used to provide 50 Hz power for refrigeration purposes on a ship which operated between Australia and far eastern ports.	The cause of premature shaft failure on a 634 kW diesel-generator set was traced to an unexpected torsional resonance of the set when operating at part load.	The dynamic behaviour was then shown to be the likely cause of excessive bearing housing wear on this and similar sets. Replacement of worn bearing housings and bearings and coupling modifications to reduce the first torsional natural frequency were implemented to resolve the problem.	N/A

71	2012	http://www.campussafetymagazine.com/article/backup-generators-prove-to-be-weak-link-during-hurricane-sandy	Will Your Generator Hold Up During an Emergency?	Hospital protection professionals, emergency managers and campus administrators learned a valuable lesson in the fall of 2012 after super storm Sandy: backup generators are critical to the continued operation of their facilities during an emergency.	Flooding caused by Hurricane Sandy affected emergency back-up power systems in a range of environments — from health-care facilities and data centres to office buildings and residential structures. New York University's Langone Medical Centre, which had to evacuate 215 patients, including 20 critically ill babies, after its backup generator failed during the storm. Coney Island Hospital in Brooklyn was forced to evacuate 180 patients, as was Bellevue Hospital and New Jersey's Palisades Medical Centre. All three evacuations were the direct result of power outages caused by Sandy.	Research indicates one in 20 hospitals are not prepared for power disruptions, according consulting firm Lawrence Associates. An incident has the potential to hit an organization's bottom line hard. Additionally, 23% of the hospitals recently inspected by the Joint Commission were not complying with standards for backup power and lighting, reports the Associated Press.	Good practice to ensure backup generators will work during an emergency, such as a hurricane or fire. -Test Generators Under Real-Life Circumstances -Location is a factor that can mean the difference between a generator working or failing. For those hospitals in areas prone to tornadoes, however, it might make the most sense to have the generator below ground, as long as there are appropriate precautions for flooding. It should also be noted that the placement of a generator around flammable materials can be hazardous. -Redundancy is another important factor with backup power location. A second generator can be placed in another part of the facility. -Electrical infrastructure changes affect generator performance. Whenever there is new construction, renovation or new systems installed at a hospital or campus research facility, there's a very good chance that the electrical infrastructure will be modified, either moderately or significantly. Personnel should make sure the generators can handle the changes, that the right circuits are put together and that all of the modifications are tested.	N/A

72	2010	http://www.bsee.gov/Inspection-and-Enforcement/Accidents-and-Incidents/acc_repo/2010/100116-pdf/	United States Department of the Interior Bureau of Safety and Environmental Enforcement Gulf of Mexico Region	Accident investigation report for diesel generator	At 1415 hours on 16 January 2010, an Operator for Maritech Resource was manually refuelling the #1 diesel generator while it was running.	During the refuelling operation, the Operator left the manual refuelling operation unattended to start the #2 generator, located approximately three feet from the #1 generator. Once the Operator started the #2 generator he detected a fire being emitted from the #1 generator. The Operator immediately utilised a 30-pound ABC fire extinguisher to extinguish the fire, removed the diesel hose from the fuel tank opening, and closed the ball valve. The #1 generator stopped on its own as a result of the fire extinguisher displacing the oxygen to the generator's intake system. It was determined that there was a momentary flash fire caused by an external source, and the most likely source of ignition was a static discharge during the refuelling process. In addition, the Operator did not complete a Job Safety Analysis (JSA), and did not review the Material Safety Data Sheet (MSDS) describing the hazards and safety precautions associated with diesel. During the diesel refuelling operation to the #1 generator, the Operator did not ground the fuel nozzle and hose to the generator package. Also, the refuelling process was conducted with the #1 generator running and unattended.	In February 2010 Maritech submitted a Safety Alert to all of its Gulf of Mexico platforms concerning the generator flash fire. The Safety Alert specified actions to be taken by Maritech employees for the elimination of future incidents of this nature as follows: * A complete review of the Material Safety Data Sheet (MSDS) and a Job Safety Analysis (JSA) will be conducted prior to each refuelling process. * The generator will be shutdown and cooled prior to refuelling, and a grounding wire and clamp will be installed on the refuelling nozzle and hose prior to refuelling. * The refuelling process will be continuously manned at all times. * An externally located diesel fuel tank with proper hose connections was installed and will be utilized during refuelling. * The Operators will be re-trained in fire fighting procedures.	N/A
73	2010	http://www.hospitalmanagement.net/features/feature98828/	Backup Power: A Vital Measure	Internet report on the vital importance of maintaining a constant energy supply to hospitals.	A surgeon in the UK had to resort to using torches to continue an operation at the Gloucester Royal Hospital during a power failure on 13 March 2010.	The failure occurred during a routine testing exercise of the hospital's back-up generators, which failed to start; some emergency lighting reportedly failed too. The incident was short-lived and staff coped well.	As part of a complete power continuity plan, consideration must be given to protecting other areas of a hospital's infrastructure, including data storage and communications, where the consequences of power disruptions may not be immediately apparent but are equally devastating.	N/A

74	2013	http://ecmweb.com/design/hurricane-sandy-turning-point-emergency-power	Hurricane Sandy: A Turning Point for Emergency Power?	Hurricane Sandy and its aftermath raise questions about the sufficiency of flooding protections for back-up power systems	Flooding caused by Hurricane Sandy affected emergency back-up power systems in a range of environments — from healthcare facilities and data centres to office buildings and residential structures.	In the worst cases, some systems were swamped, rendering gen-sets useless or too unpredictable to rely on in a critical hour of need. In others, they were temporarily disabled, leading to mere inconvenience.	New concerns raised that perhaps fundamental assumptions used to design and install back-up power in some applications and locations may be fundamentally flawed.	N/A
75	2007	http://ecmweb.com/ops-amp-maintenance/top-nine-reasons-generators-fail-start	Top Nine Reasons Generators Fail to Start	Internet article describing the leading causes of "no-start" situations among standby power systems – and what you can do to prevent them+E16:E23	Common reasons generators fail to start: Battery Failure Low Coolant Levels Low Coolant Temperature Alarms Oil, Fuel, or Coolant Leaks Controls not in Auto Air in the Fuel System Ran out of Fuel High Fuel Level Alarm Breaker Trip	Battery Failure: Eighty percent of all battery failure is related to sulfation build-up — the accumulation of lead sulphates on the plates of lead-acid batteries. This build-up occurs when the sulphur molecules in the electrolyte (battery acid) become so deeply discharged that they begin to coat the battery's lead plates. Battery failure is commonly the result of low electrolyte levels — battery plates exposed to air will immediately sulphate. Battery cells are shorted when sedimentary trays fill up with lead debris. Open cells as the result of an overcurrent of the battery system. The charger breaker being open or tripped — often the result of human error rather than actual charger failure. Dirty and loose connections.	It's important to remember that a standby generator is a mechanical and electrical device that will require service and parts to maintain proper function. In addition to exercising the generator on a monthly schedule, you should pay close attention to the following list of routine maintenance activities. COOLING SYSTEM Radiator fins must be inspected on a monthly basis and cleared of all dirt and debris. Make sure the generator is OFF prior to inspecting by shining a light through the front of the radiator. If the light doesn't shine through the fins, carefully clear the blockage. Make sure the block heater is plugged in and warm. Block heaters should be plugged in year-round, as they reduce wear on the generator's engine. Inspect hoses and the water pump for signs of wear, bulges, cracking, and leaks; check the hose clamps for tightness. FUEL SYSTEM Change fuel filters every 200 to 250 hours, depending on environmental conditions and how clean the fuel is. At a minimum, change the filter on an annual basis. Note whether or not wet spots appear around the fittings. BATTERY AND CHARGING SYSTEMS The charging gauge (or indicator light) should read OK on the battery charger. Make sure the battery and charger connections are tight, and clean any corrosion off the terminals. The battery charger must be turned off before working on the battery or the starter. ENGINE Inspect the engine for leaks and wear. Check engine belts for wear, cracking, splitting, or looseness. Check oil levels. In addition, the engine oil and oil filter should be changed annually, or every 100 to 250 hours, depending on the environment in which	N/A
						Low Coolant Levels: The most obvious cause for a low coolant level is either an external or internal leak. Pay close attention to any visible puddles of coolant during weekly inspections of the unit(s). Inspect oil for any signs of colour change or a milky texture and hoses for "crusties" — the sign of coolant seeping and additives drying up at the connection.		N/A
						Low Coolant Temperature Alarms: Low coolant temp alarms are mainly the result of faulty block heaters. A block heater will normally not cause the engine not to run. You may need to allow a generator to run for a few minutes at no load after start up so that		N/A

						the temperature comes up.	the unit is located. Check the air filter every 100 hours of operation (more frequently in dustier environments) and change the filter at least once per year. Make sure the filter canister does not contain dirt or other debris.	
						Oil, Fuel, or Coolant Leaks: Oil leaks are not in fact leaks but the result of "wet stacking" caused by excessive no-load run time whereby the engine can start to over-fuel or "wet stack" and damage the engine. Most fuel leak service calls are due to overfilling of the base tank. This is due to either human error or a failure of a pump system. The most common coolant leak occurs in the block heater hoses. Extreme temperatures on the outlet make block heaters hard on their hoses.		N/A
						Controls not in Auto: "Not in auto" messages are the direct result of human error. The obvious reason for "not in auto" situations is because the main control switch was left in the off/reset position. This usually occurs after testing or servicing of a generator. After any service is performed on a unit, always double check the generator system yourself.		N/A

						Air in the Fuel System: This is a common problem with newer generators that are not run on a regular basis. Closer tolerances within the fuel systems to meet today's emission requirements make fuel systems more susceptible to air affecting start up. Lighter low-sulphur fuel has lower flash temperature, which causes the block heater to flash off some of the fuel within the injectors. One small bubble of air within a unit injector solenoid can cause an injector not to fire at start up. If enough injectors do not fire, the engine will not start. This failure is 100% preventable by periodically running the engine during weekly inspections. The engine does not need to be run until the coolant temp comes to normal. All that is needed is enough time to verify that the engine will start, that the air is cleared from the fuel system, and that the generator comes up to voltage and frequency. This can be completed in less than 5 minutes. Any additional test running would simply burn up fuel and air quality maintenance run time.		N/A
						Ran out of Fuel: Mechanical fuel level gauges may not always be accurate. Mechanical gauges may also stick in a position until vibrations break them free. Some generators are equipped with “low level shutdown” or “critical fuel level shutdown.” These shutdowns are there to prevent the fuel system from drawing in air when running out of fuel is eminent. Bleeding air out of a fuel tank can be an extremely difficult procedure.		N/A

						High Fuel Level Alarm: High fuel level alarms are required by government regulations to prevent the overfilling of a fuel tank. The alarm should activate when the fuel tank reaches between 90% and 95% capacity. This lets the person fuelling the tank know when he or she should stop filling. Normally, there is nothing wrong with the generator when this alarm activates. On rare occasions, however, the natural thermal expansion of the fuel will cause the alarm to activate.		N/A
						Breaker Trip: Verify that nobody has accidentally pushed a remote emergency power off switch. If you find a breaker tripped, make sure you can determine the cause of the trip prior to resetting.		N/A

Appendix A.3: Database of Relevant E,C&I Engineering Operational Learning

Table 2: Operational Experience & Learning

Ref.ID	Ref. Date	Source	Source Title	Topic	Notes
R2.1		http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002005014	U.S. Nuclear Regulatory Commission, 'Aging of Nuclear Station, Diesel Generators: Evaluation of Operating and Expert Experience', August 1987		
R2.2		http://www.dieselserviceandsupply.com/Prime_vs._Standby_Power.aspx	Prime/Continuous Power vs. Standby/Backup Power		
R2.3	2011	http://www.leroy-somer.com/documentation_pdf/2327_en.pdf	Leroy Somer® Alternator Service & Operating Manual	Service & Operating Manual covering description of alternator parts & functions, installation & start-up instructions, maintenance and service schedules & procedures. Contains useful practical information illustrating typical work to be carried out on an alternator, both during plant construction and during plant operation.	
R2.4	1996	http://armypubs.army.mil/eng/DR_pubs/dr_a/pdf/tm5_685.pdf	Joint Departments of the Army and the Navy TM 5-685/NAVFAC MO-912, Operation Maintenance and Repair of Auxiliary Generators	This manual covers the various types of auxiliary power generating systems used on military installations. It provides data for the major components of these generating systems; such as, prime movers, generators, and switchgear. It includes operation of the auxiliary generating system components and the routine maintenance which should be performed on these components. It also describes the functional relationship of these components and the supporting equipment within the complete system.	
R2.5	2008	http://power.cummins.com/sites/default/files/literature/technicalpapers/PT-6014-genset-ups-compatibility-en.pdf	Cummins® Power Generation - Generator set and UPS compatibility	Documents the potential problems that can occur due to the interaction between generator sets and UPS equipment. This interaction can result in both generator set and UPS instability or malfunction, including: • Fail to "lock on" to generator power • Instability of generator • Fail to sync bypass • Instability at specific load levels • Instability at load changes • Metering errors • Loss of voltage control • Generator heating • Output voltage distortion.	
R2.6		http://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=0ahUKEwjPrca	US NRC database, 0420-E111 Emergency Diesel Generators, Chapter 13 - Case Studies and Lessons Learned		

Ref.ID	Ref. Date	Source	Source Title	Topic	Notes
		gns_KAhWDFCwKHdokBSwQFggdMAA&url=http%3A%2F%2Fpbadupws.nrc.gov%2Fdocs%2FML1122%2FML11229A183.pdf&usg=AFQjCNG-MG8k9giva4yhk2Xs1nVf7j1WYw			
R2.7		http://www.dieselserviceandsupply.com/Prime_vs._Standby_Power.aspx	Prime/Continuous Power vs. Standby/Backup Power		

Table 3: Failures and Causes

Ref.ID	Ref. Date	Source	Source Title	Topic	Notes
R3.1	2010	http://www.lsh-perkins.com/en/Services/?SId=16&SName=Troubleshooting+Guide	LSHM – Troubleshooting Guide	Perkins® Troubleshooting Guide covering 27 fault symptoms with possible causes listed for each. EC&I related faults are: 1). When the starting switch is in the (ON) position, the engine crankshaft does not rotate. 23). The starting motor does not run 24). Alternator charge rate is low or irregular 25). Alternator load is too large 26). Alternator noise	
R3.2	2009	https://stamford-avk.com/sites/default/files/literature/fault-finding-manuals/TD_FAULT_MAN_GB_JULY_2009_GB.pdf	Cummins® Generator Technologies - FAULT FINDING MANUAL for Stamford AC Generators	Detailed fault finding instructions for LV and HV alternators. Six sections covering topics as follows: • Recommended Metering and Test Instruments • Electrical Terminology • Fault Finding method 'A', for All Generators • Fault Finding method 'B', for Self-Excited Generators. • Fault Finding method 'B', for Separately Excited Generators • Parallel Operation and Fault Finding for All Generators	
R3.3	2009	http://www.irispower.com/pdf/techpapers/general%20testing/recent%20problems%20experienced%20with%20motor%20and%20generator%20windings%20-%20IEEE%20PPIC%20-%202009-	RECENT PROBLEMS EXPERIENCED WITH MOTOR AND GENERATOR WINDINGS, IEEE Paper No. PCIC-2009-6, G.C.Stone et al. 2009.	Discusses stator and rotor failures experienced in the field on HV machines, and makes recommendations to avoid premature stator and rotor failures. Stator suggestions: • Specify a Class F insulation system, but operate at Class B	

		06%20sep%202009.pdf		temperature rise. • Require a voltage endurance type test for the groundwall insulation. • Require a partial discharge test and 'black out' test on new HV winding. • Require a voltage surge test on multi-turn coils. • Require a wedging or sidepacking system that contains a follow-up restraint that ensures tightness as the slot contents shrink. Rotor suggestions: • specify a maximum winding operating temperature that is one temperature class below the thermal rating of the insulation system. • require adequate slip planes on insulated winding at the interfaces between components that will move relative to one another under mechanical and thermal expansion and contraction.	
R3.4	2007	http://generators.blogs.com/fgwservice/	FG Wilson Service and Support Blog - FG Wilson Service Bulletin on 01 Feb 2007.	Inadvertent tightening of breaker terminal bolts without temporary plastic spacer results in insulation damage and a reduction in insulation protection between phase and the chassis. Where repeated removal of connections expected, it is recommended to fit short terminal bars and phase-barriers.	
R3.5	2011	http://www.ccj-online.com/archives/2q-2011/stator-winding-failure-mechanisms/ and http://www.ccj-online.com/maughan	Stator-Winding Failure Mechanisms: Don't fall victim to these precursors of generator failure	Wealth of information on generator failures. • Endwinding vibration • Circuit ring vibration • Slot bar vibration • Winding short circuits • Contamination • Slot Partial Discharge • Endwinding Partial Discharge • Vibration sparking Several other related articles can be found on the website in the 2nd reference: • IEEE standards may not sufficiently address grounding issues in rotor, stator windings • Generator inspections, failures • There's nothing generic about generator failures • Generator condition monitor critical to avoiding catastrophic loss • Input from monitoring, inspections, tests critical for maintenance planning • Options for monitoring generator condition and their limitations • Maintaining carbon-brush collectors	
R3.6	2006	http://www.irispower.com/Upload/casestudies/216%20incidents.pdf and http://www.irispower.com/case_study.aspx	IRIS POWER CASE STUDY: 216 INCIDENTS ON-LINE PD TEST INDICATED SUSPECTED PROBLEMS	The 'success rate' of one vendor's database has been analyzed. Partial Discharge data has been received from about 3600 machines. In 216 cases, investigation of high Partial Discharge readings has been conducted and the equipment owner has provided the vendor with the results of the investigations…Partial Discharge monitoring systems appear to be finding conditions of concern on about 6% of generators where the equipment is installed. Probably no other generator monitoring system exceeds this rate of problem detection. Because of	

				the high capability of Partial Discharge monitoring continued rapid growth in the installation of Partial Discharge monitoring instrumentation should be encouraged and expected… Partial Discharge monitoring has identified many pending service problems, prevented a significant number of generator service failures, and has resulted in a major cost saving to the power generation industry. Several other case studies are available on the website in the 2nd reference.	
R3.7		http://pbadupws.nrc.gov/docs/ML1125/ML11259A101.pdf	ISL - Emergency Diesel Generator Failure Review 1999 - 2001	Report documents the review of emergency diesel generator (EDG) failures that occurred during the period of January 1, 1999, through December 31, 2001	
R3.8	2003	http://pbadupws.nrc.gov/docs/ML0301/ML030130268.pdf	NUREG/CR-6794 - Evaluation of Aging and Environmental Qualification Practices for Power Cables Used in Nuclear Power Plants	The predominant aging mechanism for power cable failure is moisture intrusion, which can degrade the dielectric properties of the insulation and result in water treeing. Other important aging mechanisms are embrittlement of the insulation due to elevated temperatures, and chafing or cutting of the insulation due to vibration or cyclic movement of the cable. The failure mode most commonly found is an electrical "ground fault," in which the cable faulted to ground from one or more of its conductors. Other less frequent failure modes are phase-to-phase fault, in which the cable faulted from one conductor to another conductor, or "low resistance," which indicates that the dielectric properties of the insulation had degraded to an unacceptable level.	
R3.9		http://pbadupws.nrc.gov/docs/ML0317/ML031710318.pdf	NUREG/CR-68 19, Vol. 1 Common-Cause Failure Event Insights - Emergency Diesel Generators	CCF Trends Overview Decreasing trend in failures after NRC Unresolved Safety Issue on SBO in 1980. Since 1985, the majority of the Complete EDG CCF events have been in the instrumentation and control sub-system. Testing was the most common method of discovery. CCF Coupling Factors Design (48%) • a single fault in a fire detection system caused all three EDGs to be unavailable, • a modification was made to the load sequencers and the EDGs would not load during subsequent testing, • low lube-oil pressure sensors were replaced with modified sensors on all EDGs at both units and within 5 days all EDGs at both NPP units experienced failures due to a large calibration shift in the sensors, • damage to all lockout relays during an attempt to shutdown the EDOs resulting in the EDGs failing to restart, • both EDGs failed due to failure of their electrical govemor caused by a burnt resistor in the power supply of the control unit, • a service water valve to EDG coolers was mis-positioned due to a	

				faulty positioner, resulting in the EDGs overheating. Maintenance (28%) • misaligned breakers during an automatic start test, • dirty contacts in the load sequencers, • painted fuel rack pivot points, • fuel oil isolated from EDGs, • drained fuel oil day tanks, • service water isolated to all EDGs during maintenance, • incorrect setpoints on a newly installed phase differential over-current relay in both EDGs. Environment (9%) • degraded relay sockets caused by vibration • sticking limit switches caused by low temperatures. Report contains an Appendix with an extensive list of failure event descriptions.	
R3.10	2005	http://pbadupws.nrc.gov/docs/ML0602/ML060200477.pdf	NUREG/CR-6890, Vol. 1 – Re-evaluation of Station Blackout Risk at Nuclear Power Plants - Analysis of Loss of Offsite Power Events: 1986-2004	On August 14, 2003, a widespread loss of the Nation's electrical power grid (blackout) resulted in LOOPs at nine U.S. commercial NPPs. As a result, the NRC initiated a comprehensive program to review grid stability and offsite power issues as they relate to NPPs. Frequency estimates for NPPs at power and shutdown operations are reported under four categories: plant-centered, switchyard-centered, grid-related, and weather-related LOOPs. For power operation, grid-related LOOPs contribute 52 percent to the total frequency of 0.036 per reactor critical year, while switchyard-centered LOOPs contribute 29 percent, weather-related LOOPs contribute 13 percent, and plant-centered LOOPs contribute 6 percent. By contrast, for shutdown operation, switchyard-centered LOOPs contribute 51 percent to the total frequency of 0.20 per reactor shutdown year, while plant-centered LOOPs contribute 26 percent.	
R3.11	2003	http://pbadupws.nrc.gov/docs/ML0317/ML031710861.pdf	NUREG/CR-6819, Vol. 4 - Common-Cause Failure Event Insights Circuit Breakers	Modes: Fail to close (55%), fail to open (45%) Discovery: Testing (60%), Demand (21%), Maintenance (11%) and Inspection (10%) Cause: Internal to Component (61%), Design/ Construction/ Installation/ Manufacture Inadequacy (18%), Operational/Human error (13%).	
R3.12		http://www.ssr-inc.com/wp-content/uploads/Managing-Hospital-EP-Programmes.pdf	Managing Hospital Emergency Power Programmes	Failure types and mitigations	
R3.13		http://www.propublica.org/article/why-do-hospitals-generators-keep-	Why Do Hospital Generators Keep Failing		

		failing			

Table 4: Reliability and Design Mitigations

R4.1		http://www.diakont.com/technical-blog/increasing-reliability-of-nuclear-reactor-edgs-through-the-use-of-intelligent-digital-control-systems/	Increasing Reliability of Nuclear Reactor EDGs Through the Use of Intelligent Digital Control Systems	Advantages and considerations of legacy Diesel Generator Control System Upgrades.	
R4.2		http://www.egsa.org/Portals/7/Documents/Powerline/Issues/powerline_2010_july-august.pdf	Maximizing Reliability in Standby Power Mission-Critical Applications	Generator set design, Genset sizing, System design, Commissioning & operator training, Maintenance and testing, Code compliance.	
R4.3		https://nrcoe.inel.gov/resultsdb/publicdocs/SystemStudies/nureg-cr-5500-vol-5.pdf	ERC - Emergency Diesel Generator Power System Reliability 1987–1993	Report documents an analysis of the reliability of emergency diesel generator (EDG) power systems at U.S. commercial nuclear plants during the period 1987–1993. Three failure modes were identified: fail to start and reach rated speed and voltage, fail to load and run for one hour, and fail to run beyond one hour.	
R4.4		www.egsa.org%2Fportals%2F7%2FDocuments%2FPowerline%2FIssues%2Fpowerline_2006_may-june.pdf	Gen-Set Controls for Electronic Engines		
R4.5		http://ecmweb.com/basics/sizing-gen-sets-large-motor-starting	Sizing Gen-Sets For Large Motor Starting		
R4.6		http://www-pub.iaea.org/books/IAEABooks/10908/Design-Provisions-for-Withstanding-Station-Blackout-at-Nuclear-Power-Plants	Design Provisions for Withstanding Station Blackout at Nuclear Power Plants	Annex V Description of Reported SBO Events including EDG faults	
R4.7		http://nrcoe.inel.gov/resultsdb/publicdocs/systemstudies/edg-system-description.pdf	INEL Emergency Diesel Generator Reliability Study		

R4.8		http://catalog.hathitrust.org/Record/003118757	Enhancement of on-site emergency diesel generator reliability		
R4.9		http://lib.dr.iastate.edu/cgi/viewcontent.cgi?article=8740&context=rtd	Reliability analysis for the emergency power system of a pressurized water reactor facility during a loss of offsite power transient		

Table 5: Electrical Components

Ref.ID	Ref. Date	Source	Source Title	Topic	Notes
R5.1	2014	http://www.yuasa.co.uk/info/technical/battery-characteristics-fault-diagnosis/	Yuasa: Battery Characteristics & Fault Diagnosis	Identifies operational problems and manufacturing faults. Operational problems: • Physical Damage • Sulphation • Wear and Tear • Deep Cycling • Overcharging • Incorrect Application • Undercharging Manufacturing Faults • Short Circuit/dead cell • Internal Break	
R5.2	2005	http://www.mpoweruk.com/failure_modes.htm	Why Batteries Fail	Outlines some of the most common cell failures and suggests preventative measures which need to be considered when specifying cells for a new battery application. Why Cells Fail • Cell design faults • Manufacturing processes out of control • Ageing • Uncontrolled operating conditions • Abuse • External Factors How Cells Fail • Active chemicals exhausted • Change in molecular or physical structure of the electrodes • Breakdown of the electrolyte	

				• Electrode plating • Increased internal impedance • Reduced capacity • Increased self discharge • Gassing • Pressure build up • Penetration of the separator • Swelling • Overheating • Thermal runaway Consequences of Cell Faults • Open circuit • Short circuit • Explosion • Fire Maximising Battery Life • Applications design • Supplier qualification • Cell qualification • Protection circuits • De-stressing the cells • Failure Prevention Design Reviews • Product qualification • Storage • Manufacturing • Planned maintenance	
R5.3	2005	http://www.mpoweruk.com/reliability.htm	Battery Reliability and How to Improve it	Discusses statistical approach using the Weibull Life Distribution Model. Includes suggested System Reliability Improvements: • Use the most reliable cells available – cell qualification and burn-in. • Lower voltage designs will be more reliable – at cell level operating slightly below maximum voltage, and at system level there will be fewer cells in series. • Increasing cycle life by reducing the stress on the cells – specify slightly higher capacity cells and provide rest periods during charging & discharging. • Use parallel strings of smaller cells - Smaller cells tend to be less stressed, small cell failure releases less energy in a failure, and failure of one parallel chain may not cause failure of the whole battery. • Control the operating environment temperature • Carry out regular maintenance	
R5.4	1986	http://prod.sandia.gov/techlib/access-control.cgi/1986/867080.pdf	NUREG/CR-4533 Program to Analyze the Failure Mode of Lead-Acid Batteries	Preliminary studies to assess lead-acid battery condition in-situ. Float voltage and internal resistance appear to predict cell capacity, at least in a relative sense. Low float voltage and high internal resistance correlate with poor capacity.	
R5.5	2015	http://batteryuniversity.com/learn/article/testing_deep_cycle_lead_acid_batteries	BU-905: Testing Lead Acid Batteries	Discusses types of battery testers, from simple single frequency conductance measurements to complex multi-frequency scans with matrix lookup to interpret measured parameters.	

R5.6	2009	http://www.artecing.com.uy/pdf/guias_megger/New%20-%20BatteryTestingGuide_en_LR.pdf	Megger – Battery testing guide	Comprehensive guide to testing lead-acid and nicad batteries. • Why backup batteries are needed • Battery types • Failure modes • Maintenance philosophies – IEEE 450, 1106 & 1188. • Practical battery testing • Frequently asked questions • Megger products overview	
R5.7	2012	http://lit.powerware.com/ll_download.asp?file=BAT11LTA_1012_final.pdf	EATON Reference handbook - The large UPS battery handbook.	Discusses flooded lead-acid VRLA batteries, dangers of thermal runaway in VRLA cells, and advantages of cell monitoring.	
R5.8	2014	http://pbadupws.nrc.gov/docs/ML1514/ML15148A418.pdf	NUREG/CR-7188 - Testing to Evaluate Extended Battery Operation in Nuclear Power Plants	Post Fukushima testing of batteries to validate performance, and to assess impact of load-shedding techniques. The projected availability of a battery can be accurately calculated using the IEEE Standard 485-2010, "IEEE Recommended Practice for Sizing Lead-Acid Batteries for Stationary Applications,"	
R5.9		www.egsa.org%2Fportals%2F7%2FDocuments%2FPowerline%2FIssues%2Fpowerline_2007_july-aug.pdf	Increase Battery Reliability in Your DC Systems to More Than Five 9s	Lead Acid Technologies Nickel Cadmium Technologies Reliability, Failure Mode, Expected Years of Service, Monitoring Systems, Maintenance Requirements	
R5.10	2010	http://www.littelfuse.com/~/media/protection-relays/white-papers/littelfuse-protection-relay-why-neutral-grounding-resistors-need-continuous-monitoring.pdf	LittelFuse® - Why Neutral-Grounding Resistors Need Continuous Monitoring	Properly applied resistance grounding can limit point-of-fault damage, eliminate transient overvoltages, reduce the risk of an arc flash, provide continuity of service with a ground fault, and provide adequate current for ground-fault detection and selective coordination. These advantages are lost if the NGR fails, which is usually to the open-circuit condition. Report contains failure examples, describes methods of detecting NGR failure, and provides some examples of the consequences of NGR failure.	
R5.11	2005	http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=1489670&url=http%3A%2F%2Fieeexplore.ieee.org%2Fxpls%2Fabs_all.jsp%3Farnumber%3D1489670	A possible mechanism for neutral grounding resistor failures	A mechanism has been identified that may account for recent failures of neutral grounding resistors in 26 kV substations owned by Public Service Electric and Gas Company (PSE&G). A neutral grounding resistor can fail due to a local, high-frequency oscillation involving the inherent inductance of the resistor and the transformer phase-to-neutral coupling capacitance. High voltages within the neutral resistor structure can be developed by the cable ring-down transients initiated by a single-line-to-ground fault on a 26 kV feeder circuit.	
R5.12	2006	http://www.wmea.net/Technical%20Papers/The%20Importance%20of%20the%20Neutral%20Grounding%20Resistor%20-%20Nov%2006.pdf	The Importance of the Neutral-Grounding Resistor	Presentation deals with High Resistance Grounding and consequences of NGR failure. Tabulates relevant standards in different US industries, and advocates NGR monitoring. Includes several case studies.	
R5.13		http://www.diakont.com/wp-content/uploads/2012/08/EDG_Contr	G. Grigoryev, "Automatic Control Systems for Nuclear Plant Emergency Diesel Generators,		

		ol_System_upgrade_WP.pdf	”Industrial Process Controls and Controllers, Volume 2006-6, pp. 31-33 (2006).		

Appendix B.1: Equipment Suppliers

Complete Generator Sets / System Integrators		
MTU Online	http://www.mtu-online.com/great-britain/mtu/?L=15	
CAT Electric Power Generation, Caterpillar	http://www.cat.com/en_GB/products/new/power-systems/electric-power-generation.html	
GE Power Generation Generators and Gas Turbines	https://powergen.gepower.com/	
Wartsila	http://www.wartsila.com/products/marine-oil-gas/engines-generating-sets	
FG Wilson	https://www.fgwilson.com/en_GB/products/new/fg-wilson/diesel-generator-sets.html?gclid=CNf_6Ou_qcoCFarpwgodA6YDJQ	
Cummings	http://power.cummins.com/high-horsepower-commercial-industrial/generators	High Horsepower Commercial Industrial
Broadcrown	http://www.broadcrown.com/	
Engines		
CAT Electric Power Generation, Caterpillar	http://www.cat.com/en_GB/products/new/power-systems/electric-power-generation.html	
CAT Electric Power Generation, Caterpillar	http://www.cat.com/en_GB/products/new/power-systems/electric-power-generation.html	
Perkins		
Mitsubishi		
MTU		
High Power Alternators		
Leroy-Sommer		
Stanford-AVK		
Meccalte		
Generator Controllers		

DeepSea	www.deepseaplc.com	
ComAp	www.comap.cz	

Appendix B.2: Database of Relevant Mechanical Engineering Good Practice for EIM&T

Ref. ID	Ref Date	Source Reference	Source Reference Title	Topic	Notes
1	2014	http://www.onr.org.uk/silicon.pdf	Office for Nuclear Regulation Licence Condition handbook	Licence Condition 28: Examination, inspection, maintenance and testing 1 The licensee shall make and implement adequate arrangements for the regular and systematic examination, inspection, maintenance and testing of all plant which may affect safety. 2 The licensee shall submit to ONR for approval such part or parts of the aforesaid arrangements as ONR may specify. 3 The licensee shall ensure that once approved no alteration or amendment is made to the approved arrangements unless ONR has approved such alteration or amendment. 4 The aforesaid arrangements shall provide for the preparation of a plant maintenance schedule for each plant. The licensee shall submit to ONR for its approval such part or parts of any plant maintenance schedule as ONR may specify. 5 The licensee shall ensure that once approved no alteration or amendment is made to any approved part of any plant maintenance schedule unless ONR has approved such alteration or amendment. 6 The licensee shall ensure in the interests of safety that every examination, inspection, maintenance and test of a plant or any part thereof is carried out. a) by suitably qualified and experienced persons; b) in accordance with schemes laid down in writing; c) within the intervals specified in the plant maintenance schedule; and d) under the control and supervision of a suitably qualified and experienced person appointed by the licensee for that purpose. 7 Notwithstanding the above paragraphs of this condition ONR may agree to an extension of any interval specified in the plant maintenance schedule. 8 When any examination, inspection, maintenance or test of any part of a plant reveals any matter indicating that the safe operation or safe condition of that plant may be affected, the suitably qualified and experienced person appointed to control or supervise such examination, inspection, maintenance or test shall bring it to the attention of the licensee forthwith who shall take appropriate action and ensure the matter is then notified, recorded, investigated and reported in accordance with arrangements made under Condition 7. 9 The licensee shall ensure that a full and accurate report of every examination, inspection, maintenance or test of any part of a plant indicating the date thereof and signed by the suitably qualified and experienced person appointed by the licensee to control and supervise such examination, inspection, maintenance or test is made to the licensee forthwith upon completion of the said examination, inspection, maintenance or test.	
2	2015	http://www.onr.org.uk/operational/tech_asst_guides/tast009.pdf	Examination, Inspection, Maintenance and Testing of Items Important to Safety, Nuclear Safety Technical Assessment Guide, NS-TAST-GD-009 - Revision 02	This Technical Assessment Guide (TAG) directly addresses those ONR Safety Assessment Principles (SAPs) which relate to in-service and throughout facility life Examination, Maintenance, Inspection and Testing (EMIT); EMT.1 to EMT.8 (Reference ID 3 below). The TAG has been written primarily in general terms so that it applies to all engineering disciplines. It should also be noted that EMIT is considered to be an integral part of the operation of a nuclear facility.	
3	2014	http://www.onr.org.uk/saps/saps2014.pdf	Safety Assessment Principles for Nuclear Facilities	EMT.1 Identifion of requirements: Safety requirements for in-service testing, inspection and other maintenance procedures and frequencies should be identified in the safety case. EMIT.2 Frequency: Structures, systems and components should receive regular and systematic examination, inspection, maintenance and testing as defined in the safety case. EMIT.3 Type-testing: Structures, systems and components should be type tested before they are installed to conditions equal to, at least, the most onerous for which they are designed. EMIT.4 Validity of equipment qualification: The continuing validity of equipment qualification of structures, systems and components should not be unacceptably degraded by any modification or by the carrying out of any maintenance, inspection or testing activity. Commissioning and in-service inspection and test procedures should be adopted that ensure initial and continuing quality and reliability. EMT.6 Reliability claims: Provision should be made for testing, maintaining, monitoring and inspecting structures, systems and components (including portable equipment) in service or at intervals throughout their life, commensurate with the reliability required of each item. EMT.7 Functional testing: In-service functional testing of structures, systems and components should prove the complete system and the safety function of each functional group.	

Ref. ID	Ref Date	Source Reference	Source Reference Title	Topic	Notes
				EMT.8 Continuing reliability following events: Structures, systems and components should be inspected and/or re-validated after any event that might have challenged their continuing reliability.	
4	2007	http://www.nrc.gov/reading-rm/doc-collections/reg-guides/power-reactors/rg/01-009/01-009.pdf	Office of Nuclear Regulatory Research Regulatory Guide 1.9: Application and Testing of Safety-Related diesel Generators in Nuclear Power Plants	The reliability of emergency diesel generators can be one of the main factors affecting the risk of core damage from a station blackout event. Thus, both attaining and maintaining the high reliability of emergency diesel generators at nuclear power plants contribute greatly to reducing the probability of station blackout. Regulatory Guide 1.155, “Station Blackout” , (Ref ID 5) calls for the use of the reliability of the diesel generator as one of the factors in determining the length of time a plant should be able to cope with a station blackout. If all other factors (i.e., redundancy of emergency diesel generators, frequency of LOOP, and probable time needed to restore offsite power) remain constant, a higher reliability of the diesel generators will result in a lower probability of a station blackout, with a corresponding decrease in coping duration for certain plants. The design of the emergency diesel generators should also incorporate high operational reliability, and this high reliability should be maintained throughout their lifetime by initiating a reliability program that is designed to monitor, improve, and maintain reliability. Increased operational reliability can be achieved through appropriate testing and maintenance, as well as an effective root cause analysis of all emergency diesel generator failures. This guide provides explicit guidance in the areas of preoperational testing, periodic testing, reporting and recordkeeping requirements, and valid demands and failures. The preoperational and periodic testing provisions set forth in this guide provide a basis for taking the corrective actions needed to maintain high in-service reliability of installed emergency diesel generators. The database developed will assist ongoing performance monitoring for all emergency diesel generators after installation and during service.	
5	1988	http://adamswebsearch.nrc.gov/webSearch2/view?AccessionNumber=ML003740034	Examination, Inspection, Maintenance and Testing of Items Important to Safety: Nuclear Safety Technical Assessment Guide, NS-TAST-GD-009 - Revision 02	The reliability of EDGs can be one of the key factors affecting the risk of core damage (due to station blackout event potential). Assuring the high reliability and availability of EDGs at nuclear power plants contributes greatly to reducing the probability of a station blackout event and improving overall nuclear plant safety. Section 1.2 of the Regulatory Guide on station Blackout covers "Reliability Programs" The reliable operation of onsite emergency AC power sources should be ensured by a reliability program designed to maintain and monitor the reliability level of each power source over time for assurance that the selected reliability levels are being achieved. An EDG reliability program would typically be composed of the following elements or activities (or their equivalent): 1. Individual EDG reliability target levels consistent with the plant category and coping duration 2. Surveillance testing and reliability monitoring programs designed to track EDG performance and to support maintenance activities 3. A maintenance program that ensures that the target EDG reliability is being achieved and that provides a capability for failure analysis and root-cause investigations 4. An information and data collection system that services the elements of the reliability program and that monitors achieved EDG reliability levels against target values 5. Identified responsibilities for the major program elements and a management oversight program for reviewing reliability levels being achieved and ensuring that the program is functioning properly.	
6	2014	http://www.wenra.org/media/filer_public/2014/09/19/wenra_safety_reference_level_for_existing_reactors_september_2014.pdf	WENRA Safety Reference Levels for Existing Reactors	Western European Nuclear Regulators’ Association (WENRA) safety reference levels (RLs) for operating nuclear power plants (NPPs). The RLs reflect expected practices to be implemented in the WENRA countries. The emphasis of the RLs is nuclear safety, primarily focussing on safety of the reactor core and spent fuel. Section 11 Issue K covers Maintenance, In-Service Inspection and Functional Testing and is covered in three sections K1. Scope and objectives K2. Programme establishment and review K3. Implementation	
7	2014	http://shop.standards.ie/nsai/details.aspx?ProductID=1788723	KTA 3702-2000 Emergency Power Generating Facilities With Diesel-generator Units In Nuclear Power Plants	This safety standard applies to emergency power generating facilities with Diesel Generator Units. Section 8 covers In Service Inspections Section 9 Covers Operation, Servicing and Repair.	Standard would need to be purchased.

Ref. ID	Ref Date	Source Reference	Source Reference Title	Topic	Notes
8	2015	http://www.fairbanksmorse.com/parts_service/	Fairbanks Morse Engine OEM Replacement Engine Parts	Internet Company Brochure. Only Fairbanks Morse Engine OEM replacement parts can keep stationary generator sets productive and efficient. From proprietary metallurgical specifications to exacting machining tolerances, genuine engine parts ensure the optimal performance and long service life of your Fairbanks Morse stationary diesel engine generator set.	
9	2012	http://www.mtu-online.com/fileadmin/fm-dam/mtu-global/technical-info/operating-instructions/neu_17_08_2012/en/MS150054_02E.pdf	MTU: Operating Instructions for 12 and 16V 4000 G73 engine Chapter 5 Maintenance	Section 5.1 Maintenance task reference table provides maintenance tasks and intervals for this product which are defined in the Maintenance Schedule. The Maintenance Schedule is a stand-alone publication.	
10	2014	http://www.munichre.com/site/hsb/get/documents_E1563157526/hsb/assets.hsb.group/Documents/Knowledge%20Center/447%20%20%20Recommended%20Practice%20for%20Maintaining%20Emergency%20and%20Standby%20Engine-Generator%20Sets.pdf	Maintaining Emergency and Standby Engine-Generator Sets	This recommended practice applies to emergency and standby power systems from several hundred kilowatts (kW) to several megawatts (MW), provided the individual engine-generator sets are no larger than 2 MW net power output each. A good maintenance program can be compared to routine maintenance of a car: checking fluid levels, changing lubrication oil, coolant and fuel, and testing the starting system, including the batteries. Regularly running the engine-generator will keep it working at optimum performance levels. Spare air, oil, and fuel filters should be also kept on hand in case one is needed in short notice. Keeping a maintenance log is also important. A record of all maintenance, inspections, fluid levels, and test results will enable more accurate planning of future maintenance. Well-kept logs may also be important for warranty and insurance purposes. These practices are meant to complement the Original Equipment Manufacturer (OEM) maintenance procedures. A maintenance program should be based on the OEM recommended maintenance	
11	2015	http://www.wealdpower.com/news/shownews.php?lang=en&id=25	Fujian Weald Industry Co.,Ltd Diesel engine maintenance	Weald Power, a professional manufacturer of power generators in China, Internet article highlighting a generic diesel engine maintenance program.	
12	1991	http://www.dtic.mil/dtic/tr/fulltext/u2/a445496.pdf	Standard Commercial Ship Test and Inspection Plan, Procedures, and Database NSRP 0534 Project 6-95-1	TP # 8605 - Emergency Diesel Generator Purpose and Equipment tested To demonstrate the proper installation and operation of the Emergency Diesel Generator. The operational test of the system will prove proper operation of the following equipment: 1.1 One (1) 600Kw Emergency Diesel Generator set and associated systems 1.2 One (1) Electric driven Jacketwater Pump (EDG) 1.3 One (1) Emergency Switchboard 1.4 One (1) Emergency Diesel Generator Marine Gas Oil Day Tank	
13	2010	https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/282343/mgn052.pdf	Maritime Safety Agency: MGN 52 Testing of Emergency Sources of Electrical Power	Marine Guidance Note: Notice to Owners, Masters, Skippers and Crews of Merchant Ships and Fishing Vessels: Investigation into marine casualties has indicated that a number of incidents have occurred in which the emergency source of electrical power has not operated correctly following the loss of main power. The purpose of this Marine Guidance Note is to remind those responsible for the operation of ships that the Regulations require periodic testing of the complete emergency electrical system including any automatic starting arrangements.	
14	1995	http://www.techstreet.com/ieee/products/vendor_id/594	IEEE 387-1995 IEEE Standard Criteria for Diesel-Generator Units Applied as Standby Power Supplies for Nuclear Power Generating Stations	This standard describes the criteria for the application and testing of diesel-generator units as Class 1E standby power supplies in nuclear power generating stations.	Report would need to be purchased.

Ref. ID	Ref Date	Source Reference	Source Reference Title	Topic	Notes
15	2016	http://www.nfpa.org/codes-and-standards/document-information-pages?mode=code&code=110	National Fire Protection Association (NFPA) 110: Standard for Emergency and Standby Power Systems	This standard covers performance requirements for emergency and standby power systems providing an alternate source of electrical power in buildings and facilities in the event that the normal electrical power source fails. Systems include power sources, transfer equipment, controls, supervisory equipment, and accessory equipment needed to supply electrical power to the selected circuits. NFPA 110 presents installation, maintenance, operation, and testing requirements as they pertain to the performance of the emergency or standby power supply system (EPSS) up to the load terminals of the transfer switch. Specific topics include definitions of the classification of EPSS; energy sources, converters, inverters, and accessories; transfer switches and protection; installation and environmental considerations; and routine maintenance and operational testing.	Standard would need to be purchased.
16	2014	http://www.nfpa.org/codes-and-standards/document-information-pages?mode=code&code=70	National Fire Protection Association (NFPA) 70: National Electrical Code (NEC) Article 700,	Standard covers the electrical safety of the design, installation and operation and maintenance of emergency systems for illumination and /or power to required facilities when the normal electrical supply or system is interrupted. Chapter 4 Equipment for General Use section 445 contains information on Generators	Standard would need to be purchased.
17	2014	http://www.facilitiesnet.com/powercommunication/article/Standby-Generators-Require-Regular-Testing-Maintenance-Exercising-And-Inspection-Facilities-Management-Power-Communication-Feature--14801	Standby Generators Require Regular Testing, Maintenance, Exercising, And Inspection	Internet article: Part 1: Standby Generators Require Regular Testing, Maintenance, Exercising, And Inspection Part 2: Keys To Backup Power System Success: Features, Flexibility, And Redundancy Part 3: Exercise Standby Generators To Keep Them In Fighting Shape Part 4: Preventive Maintenance Is Critical To Dependable Standby Generators For optional or life-safety emergency standby power systems, failure to start or failure to run can have enormous consequences. Regular testing, maintenance, exercising, and inspection can help keep standby generators ready to perform when needed. For optional standby generators (not required by life-safety code), critical loads supported by the generator system typically include data centre and call centre equipment such as UPS systems, cooling, phone systems, and desktop equipment (computers, etc.). For emergency standby generators (required by life-safety code), critical loads supported by the generator system typically include emergency lighting, fire alarm systems, fire pumps, and elevators. Life-safety generators are also sometimes used to additionally support optional loads, such as data centres; however, in this case the life-safety loads take precedence over the optional loads. Good design, quality equipment, trained operating personnel, commissioning, regular inspections and exercising, preventative maintenance, trained service support, and performance testing are all key to reliable performance.	
18	2014	http://www.hitachi-hgne-uk-abwr.co.uk/downloads/2014-08-28/UKABWR-GA91-9101-0101-05007-P-RevA.PDF	UK ABWR Generic Design Assessment Generic Pre-Construction Safety Report Sub-chapter 5.7 : Monitoring, Inspections and Testing	This sub-chapter describes the examination, maintenance, inspection and testing (EMIT) to be carried out to ensure that the required safety and reliability will be achieved throughout Facility Lifecycle of UK ABWR. The EMIT are carried out as the measures to verify that performance of Structures, Systems and Components (SSCs) satisfy the safety features intended in the design. EMIT verify if the performance requirements for the safety features prescribed with respect to claims and arguments in the Pre-Construction Safety Report(PCSR) are duly satisfied. each SSCs is examined for its conformance with the requirements of codes and standards prescribed according to the relevant safety classification and quality classification	
19	2014	https://www.wbdg.org/ccb/AF/AFETL/etl_13_4.pdf	Department of the Air Force: Engineering Technical Letter (ETL) 13-4 (Change 1): Standby Generator Design, Maintenance, and Testing Criteria	This Engineering technical letter provides criteria for design, maintenance, and testing of Air Force emergency and standby generator systems.	
20	2009	http://www.health.state.mn.us/divs/fpc/Gensets2.pdf	Inspection and maintenance of emergency generators	NFPA 101(00), Sec. 7.9.2.3 requires that emergency generators be installed, tested and maintained in accordance with NFPA 110, Standard for Emergency and Standby Power Systems. Provisions dealing with maintenance and testing of emergency generators can be found in NFPA 99(99), Sec. 3-4.4. This section starts out by referencing NFPA 110, but also deals with such issues as: Testing intervals, Test conditions, Personnel qualifications, Maintenance and testing of circuitry, and Maintenance of batteries	
21	2008	http://www.osti.gov/scitech/servlets/purl/491576	WSRC-TR-96-0393, Rev. 1 Backup Power Working Group Best Practices Handbook for Maintenance and Operation of Engine Generators, Volume 1 (U)	Chapters in this handbook are intended to supplement original equipment manufacturer (OEM) information and practices primarily for stationary gasoline and diesel engines. The guidelines presented were based on available literature and the experience of the Engine Generator Subcommittee members. Chapter 1 covers Design, Procurement, Storage, Handling and Testing of Diesel Fuel Oil to be Used in DOE Backup Power Supplies Chapter 4 covers Installation, Design, and Maintenance of Engine Cooling Water and Jacket Water Systems	-

Ref. ID	Ref Date	Source Reference	Source Reference Title	Topic	Notes
22	2007	http://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&frm=1&source=web&cd=11&ved=0CCcQFjAAOApqFQoTCJ2Q3Jb5wcgCFUwzPgodTDcLHw&url=http%3A%2F%2Fwww.powersystems.cummins.com%2F_literature_98390%2FPower_System_Maintenance_Brochure&usg=AFQjCNHzcw9dMaO80DmBm-MCzq5DupDYaA	Technical information from Cummins Power Generation; Maintenance is one key to diesel generator set reliability	By following generally recognised diesel maintenance procedures and specific manufacturer recommendations for the required application, you'll be assured that your standby power system will start and run when you need it most. Most maintenance is preventive in nature consists of the following operations: • General inspection • Lubrication service • Cooling system service • Fuel system service • Servicing and testing starting batteries • Regular engine exercise	
23	2006	http://dspace.mit.edu/bitstream/handle/1721.1/35682/76882552-MIT.pdf?sequence=2	Maintenance Practices for Emergency Diesel Generator Engines Onboard United States Navy Los Angeles Class Nuclear Submarines	This thesis examines more than 7,000 maintenance records dated 1989 to 2005 for emergency diesel generator engines onboard Los Angeles class nuclear submarines. This class of submarines, which features the Fairbanks Morse 8-cylinder air-started opposed-piston diesel engine, is expected to continue to operate until at least 2020. An analysis of corrective and routine maintenance tasks was conducted. Analysis included the diesel engine as well as its subsystems of diesel lube oil, diesel freshwater, diesel seawater, diesel air start, and diesel fuel oil. The analysis centered on maintenance task times and costs. Findings; Diesel engine maintenance actions adversely affecting operational availability, on average: • Require more labour hours • Utilise more expensive repair parts • Require more expensive labour • Are not necessarily handled more expeditiously than other maintenance actions; and can take slightly longer to reconcile. Most diesel engine maintenance actions are inexpensive and require minimal effort. Diesel engine availability is difficult to measure. What can be measured varies greatly from submarine to submarine.	
24	2013	http://ecmweb.com/ops-amp-maintenance/implementing-standby-generator-maintenance-program-diesel-engines	Electrical Construction and Maintenance Implementing a Standby Generator Maintenance Program for Diesel Engines Oct 16, 2013 David Kovach Electrical Construction and Maintenance	Internet article highlights maintenance procedures that need to be performed on a regular basis. In addition to these checks, exercising the power system under load on a weekly or monthly basis ensures that the generator set and its system of controls and transfer switches is operating as designed. Because of the durability of diesel engines, most maintenance is preventive in nature and consists of the following operations: • General inspection • Lubrication service • Cooling system service • Fuel system service • Servicing and testing starting batteries • Regular engine exercise	
25	2012	https://www.archsd.gov.hk/media/11425/e210.pdf	Testing and commissioning procedure for emergency generator installation in government buildings of the Hong Kong special administrative Region	This Testing and Commissioning (T&C) Procedure aims to lay down the minimum testing and commissioning requirements to be carried out on Emergency Generator Installation in Government Buildings of the Hong Kong Special Administrative Region (HKSAR). Such requirements are applicable to both new installations upon completion and existing ones after major alteration.	
26	2009	http://www.aip.com.au/pdf/Diesel_fuel_Back-up_Generation.pdf	Diesel Fuel & Back-Up Generation Issues for CEOs, Risk Managers and Diesel Users	Diesel back-up generators are a common and effective way of protecting organisations against the economic and social consequences of power disruptions. This paper provides information and general advice on issues organisations should be aware of to ensure that back-up systems operate effectively when most needed. Section 2 examines the issues an organisation needs to consider in the maintenance and testing of back-up generators and their fuel. For ease of reference, checklists have been developed to assist organisations in gaining a better understanding of their generator and fuel requirements.	
27	2012	http://www.ihea.org.au/files/vic/ppt_-_bruce_sanderson.pdf	Striving for availability Management of diesel-engine driven emergency power supply systems	Presentation covering routine maintenance and operational testing of Emergency Power Supply System	

Ref. ID	Ref Date	Source Reference	Source Reference Title	Topic	Notes
28	2012	http://pbadupws.nrc.gov/docs/ML1122/ML11229A163.pdf	U.S. Nuclear Regulatory Commission; Chapter 11 Emergency Diesel Generator Qualification, Site acceptance and surveillance testing	Presentation covering: 1. How EDGs are type-qualified for nuclear power plant service. 2. Installation, break-in, inspection, and full load run by supplier. 3. The licensee's pre-operational test program to verify EDG performance and establish critical baseline data. 4. The licensee's ongoing surveillance testing of their EDG's. 5. A typical EDG surveillance run by the licensee, including control of KW and KVAR loading when on the grid. 6. Comments on the relevance of this material to EDG selection/operation.	
29	2012	http://pbadupws.nrc.gov/docs/ML1122/ML11229A172.pdf	U.S. Nuclear Regulatory Commission; Chapter 12 EDG Performance Monitoring and Maintenance	Presentation covering: 1. The difference between Prescriptive (periodic) and Predictive (condition-based) EDG maintenance, and how licensees have benefited from the trend to a Predictive approach. 2. An overview of key regulatory requirements for maintenance, including the "NRC Maintenance Rule." 3. Monitoring, trending, and analysis of key EDG parameters, including specific engine and support system values during runs, as well as the fuel oil, lubricating oil, cooling water, etc. 4. The importance of baseline data, parameter trending, competent analysis, and follow-up to assure effectiveness. 5. The necessity for observations before, during and after EDG runs, and also in conjunction with any maintenance done on (or even in the vicinity of) the EDG. 6. Some applications of EDG monitoring systems…including the human senses. 7. Information on the contribution of each EDG subsystem to the failure rate, and some observations regarding that.	
30	2007	http://www.nrc.gov/reading-rm/doc-collections/reg-guides/power-reactors/rg/01-009/01-009.pdf	U.S. Nuclear Regulatory Commission; Regulatory Guide 1.9 Application and testing of safety related diesel generators in Nuclear Power Plants	This guide provides explicit guidance in the areas of preoperational testing, periodic testing, reporting and recordkeeping requirements, and valid demands and failures. The preoperational and periodic testing provisions set forth in this guide provide a basis for taking the corrective actions needed to maintain high in-service reliability of installed emergency diesel generators. The database developed will assist ongoing performance monitoring for all emergency diesel generators after installation and during service.	
31	2014	http://facilityexecutive.com/2014/08/emergency-generators-and-load-banks/	Testing Emergency Generators: Contributed by Electrical Generating Systems Association	Internet article highlighting how a load bank is an important tool that will test a complete generator set system up to its rated load. There are two potential problems that can compromise the reliability of the standby generator set. The first is that without testing the complete system under expected working conditions, any problems in the system will not be uncovered until there is a utility power failure. Second, continued operation under no-load conditions can lead to "wet stacking" of diesel engines. This is a condition resulting from condensed fuel and oil particles accumulating around the injectors, valves, and exhaust system, reducing the engine's ability to generate its rated load.	
32	2009	http://www.curtisengine.com/docs/Presentation.pdf	Curtis Engine: Emergency Power System Best Practices	Company presentation highlighting why generators fail and how this could be avoided by; • Regular engine exercising • following a preventative maintenance and testing programme, • Periodic load testing • annual fuel cleaning and filtering	
33	2010	http://www.fueltechnologiesinternational.com/clean-fuel-for-your-emergency-power-supply-eps.html	Fuel Technologies International Clean Fuel For Your Emergency Power Supply (EPS)	Internet article covering four simple steps that need to be put in place to assure clean fresh fuel for the prime mover in an Emergency Power System •Have your fuel tested annually •Kill the bugs (microbial growth) •Treat the fuel for stability •Remove water and sediment regularly	
34	2013	http://www.plantengineering.com/single-article/structured-maintenance-ensures-genset-reliability/746cf871f6c5cd5639fc3bc2e3813398.html	Plant Engineering: Structured maintenance ensures genset reliability	Company internet article describing how Consulting engineers are in an excellent position to recommend structured maintenance programs to their clients. Consulting engineers can do their clients a great service by encouraging them to incorporate formal, computer-aided generator maintenance programs into their projects at the outset and underscoring the importance of following them to the letter. Because it is difficult for companies with only one or two generators to maintain such programs in house, discussing generator maintenance services can also provide an opportunity for qualified consulting engineering firms to offer these services to their clients—or to partner with third-party vendors who specialize in this important process.	

Ref. ID	Ref Date	Source Reference	Source Reference Title	Topic	Notes
35	2015	http://www.generatorassociates.com/maintenance.htm	Generator and UPS maintenance	Company website. Regular servicing of both diesel and gas generators used for either prime or backup (emergency) power, as well as uninterruptible power supply systems is crucial to optimising the life span of your power protection solution. Scheduled and routine maintenance is the only way to ensure the equipment is working at its peak potential, and always ready for when it is needed. As a guide for standby generators, we recommend that the generator is serviced twice a year. These are known as A and B services, or Wet and Dry. The tasks undertaken during an A service visit cover equipment checks, oil and filter changes and test runs.	
36	2011	http://www.criticalpowersupplies.co.uk/filedata/0000/1248/File-1378137697_1_.pdf	Hyundai: Diesel Generator Operation and Maintenance Manual	Hyundai series diesel engine generator sets are widely used in the fields of construction, communication, banking business, mining, leasing industry and other special sites. Used as auxiliary power supply to solve energy interruptions that may cause serious problems to people, physical and /or financial damage or to face consumption peaks. Chapter 4 covers the general maintenance for the engine, alternator, control panel and start battery.	
37	2015	http://www.globalpwr.com/generator_services/preventive-maintenance/	Global Power Supply: Preventative Maintenance	Company website provides a Generator Preventive Maintenance Scope of Work in three levels covering ; Level One 77 Point Operational Inspection Performed as Needed (Monthly, Quarterly, or Semi-Annually) Level Two Service, Typically performed annually or as operating hours require Level Three Service, Typically performed at 3 year interval	
38	2014	http://ecmweb.com/blog/testing-generators-portable-load-bank	Electrical Construction and maintenance Blob: Testing Generators with a Portable Load Bank	Internet blog recommended procedure to follow for a load bank test: a. Start and run the generator until the water temperature stabilizes. b. Transfer all manual or automatic transfer switches to the emergency source. c. Step load the generator with the load bank until the desired load is reached. d. Remove the load bank load first, after the test. e. Transfer all transfer switches back to the normal position. f. Allow the generator to cool down according to manufacturers' guidelines.	
39	2015	http://www.emersonnetworkpower.com/documentation/en-US/Products/Load-Banks/Documents/White%20Papers/Load_Bank_Testing_White_Paper.pdf	Emerson Network Power: Load Bank Testing	Internet brochure describing how load bank testing provides facilities executives with numerous benefits. For new buildings, the load bank testing validates that the backup generation system is performing to design specifications. For existing structures, load bank testing makes sure that modifications or remodelling adjustments have not altered the backup generator's operation. Or, if they have, load bank testing puts facility executives in a position to install additional or modified backup generator sets before any power failures occur.	
40	2003	http://www.mass.gov/anf/docs/dcam/mafma/manuals/emergency-power-testing-programs-for-hospitals.pdf	Managing Hospital Emergency Power Testing Programs	This monograph examines a comprehensive approach to Managing Hospital Emergency Power Supply System (EPSS) testing programs in light of the increasing complexity of hospital infrastructures and operational constraints. All hospitals must have an emergency power testing program that includes generator load testing and EPSS maintenance. This comprehensive and proactive utility management program approach uses lessons learned from the testing to improve the hospital's facilities, EPSS reliability and training.	
41	2012	https://www.vdh.virginia.gov/OLC/Laws/documents/2012/pdf/VDH%20and%20SFMO%20Guidance%20on%20Generator%20Testing%20in%20Nursing%20Facilities.pdf	The State Fire Marshal's Office and the VDH/Office of Licensure and Certification: Generator Testing in Nursing Facilities	Given the delicate manner in which health care services are provided in nursing facilities, facilities should have a frequently inspected (equipment off) and exercised (tested with the equipment on and running) on-site Level 1 EPSS with the capacity for enough fuel to run the Level 1 EPSS for at least seventy-two (72) hours should the facility experience a loss of power. General Inspection and Testing of the EPSS This guidance suggests a routine maintenance and operational testing program based on all of the following: 1. Manufacturer's recommendations; 2. Equipment instruction manuals; 3. Minimum requirements of the NFPA 110; and 4. The authority having jurisdiction.	
42	2005	http://specs4.ihserc.com/Document/Document/ViewDoc?docid=PGIXIBAAAAAAAAAA	BS ISO 8528-6:2005; Reciprocating internal combustion engine driven alternating current generating sets — Part 6: Test methods	This part of ISO 8528 specifies the test methods to be used for characterizing an entire generating set. It applies to alternating current (a.c.) generating sets driven by reciprocating internal combustion (RIC) engines for land and marine use, excluding generating sets used on aircraft or to propel land vehicles and locomotives. For some specific applications (e.g. essential hospital supplies, high-rise buildings) supplementary requirements may be necessary. The provisions of this part of ISO 8528 are intended as a basis for establishing any supplementary requirements.	

Ref. ID	Ref Date	Source Reference	Source Reference Title	Topic	Notes
43	1997	http://specs4.ihserc.com/Document/Document/Details?docid=SBJVBFAAAAAAAAAA	ISO 8528-12; Reciprocating Internal Combustion Engine Driven Alternating Current Generating Sets: Part 12 Emergency Power Supply to Safety Services	This part of ISO 8528 applies to generating sets driven by reciprocating internal-combustion (RIC) engines for emergency power supply to safety services. It applies, for example, to safety equipments in hospitals, high-rise buildings, public gathering places etc. This part of ISO 8528 establishes the special requirements for the performance, design and maintenance of power generators used in the applications referred to above and taking into account the provisions of ISO 8528-1 to ISO 8528-6 and ISO 8528-10	Standard would need to be purchased.
44	2015	http://www.nfpa.org/codes-and-standards/document-information-pages?mode=code&code=37&tab=about	NFPA 37: Standard for the Installation and Use of Stationary Combustion Engines and Gas Turbines	This standard establishes criteria for minimizing the hazards of fire related to the installation and operation of stationary combustion engines and stationary gas turbines that are fuelled by liquid or gaseous fuels and are used as prime movers for emergency generators, fire pumps, and stand-by and peak power systems. Requirements address system installation, fuel supplies, lubricating systems, engine exhaust systems, control and instrumentation, and fire protection features.	Standard would need to be purchased.
45	2015	http://shop.csa.ca/en/canada/general-standards/c282-09/invt/27012072009	CSA C282 Emergency Electrical Power Supply for Buildings	This consensus based Standard provides design, installation, operation, maintenance and testing requirements for emergency electrical power generators and associated equipment for use by generator set designers, manufacturers, installation contractors, maintenance contractors, building inspectors and commissioners in buildings where emergency power generators are mandated by the National Building Code of Canada. The Standard applies to oil-fired, natural gas and propane-fired emergency electrical power generators and is referenced in the National Building Code of Canada and the National Fire Code of Canada. The requirements of this standard are widely used by Federal, Provincial and municipal building inspectors and fire safety inspectors.	Standard would need to be purchased.
46	2010	http://www.neimagazine.com/features/featurethe-power-behind-power/	Nuclear Engineering International: The power behind power	Emergency diesel backup generators are vital for safety; every nuclear power reactor has at least two of them. So as new-build begins to take off and the market for replacements heats up, suppliers are gearing up and battling for orders.	
47	2011	http://www.toromontcat.com/powersystems/pdf/newsletter/Emergency%20Generators%20-%2010%20Sec%20Starting.pdf	Emergency Generators – 10 Second Starting	Some emergency and standby power applications require the ability to start up and accept electrical loads in less than 10 seconds to meet CSA 282-09 & CSAZ32. The specifications prepared by the consultant engineers or the end users shall include the manufacturer's recommendations to successfully meet the code requirements. This internet article summarises, as a minimum, the "must haves" to improve the ability of fast generator set starting.	
48	2010	http://www2.schneider-electric.com/documents/support/white-papers/wp_healthcare_automoting-energency-power.pdf	Schnieder Electrical: Automating Emergency Power Supply System Testing in Hospitals	This White Paper describes how Improper Testing Can Cause Reliability to Decrease and highlights the Advantages of Automated EPSS Testing. To avoid EPSS failure, it is crucial that diesel engines used for emergency backup power in hospitals get tested and exercised at regular intervals within the parameters dictated by regulatory bodies and engine manufacturers. Automated testing and monitoring helps point out problems during testing rather than during an outage. As such, the system's overall mean time between failures (MTBF) can be improved, giving patients, staff and administrators peace of mind, so they can rest assured that the EPS system is ready to power the hospital whenever required.	
				IS 3218:2009 Fire Detection and Alarm Systems for Buildings: System Design, Installation Servicing and Maintenance	
				IS 3217:2008 Emergency Lighting and IS 3218:2009 Fire Detection and Alarm Systems for Buildings: System Design, Installation and Servicing and manufactures instructions should also be followed.	

Ref. ID	Ref Date	Source Reference	Source Reference Title	Topic	Notes
				IS EN 12845:2004 + A2: 2009 Fixed fire fighting systems: Automatic sprinkler systems; Design, installation & maintenance	
				BS 9999:2008: Code of practice for fire safety in the design, management and use of buildings	
				IS EN 50073:1999 Guide for selection, installation, use and maintenance of apparatus for detection and measurement of combustible gases or oxygen.	
		-		Standards are set by national bodies and codes including the IEEE, ASME (USA), RCCE and RCCM codes (France), the CSA (Canada), KTA (Germany), GOST and ROSTECHNADZOR (Russia) and YVL (Finland). The Institute of Electrical and Electronics Engineers (IEEE) Standard 387-1995 is a benchmark that is widely referenced for principal design criteria and qualification and testing guidelines, to ensure that generators meet performance requirements.	

Appendix B.3: Database of Relevant E,C&I Engineering Good Practice for EIM&T

Table B.6: Obsolescence and Upgrades

Ref. ID	Source Reference	Source Title	Topic	Notes
R1.1	https://www.basler.com/Products/Genset-Controls/Retrofits/Retrofit-Options	Genset Control Retrofit Options		
R1.2	http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002000568	Plant Engineering: Emergency Diesel Generator Excitation System End of Expected Life Guidance	Using historical operating data, probabilistic failure models, and subject matter expert input, the report describes the onset of end-of-life failure modes, problem areas, obsolescence issues and recommendations for retrofits, condition monitoring, and assessment of the system's vulnerability to an end-of-life situation.	
R1.3	http://www.nrc.gov/reading-rm/doc-collections/nuregs/contract/cr6928/	Industry-Average Performance for Components and Initiating Events at U.S. Commercial Nuclear Power Plants (NUREG/CR-6928)	Report characterizes current industry-average performance for components and initiating events at U.S. commercial nuclear power plants.	
R1.4		U.S. Nuclear Regulatory Commission, 'Aging of Nuclear Station, Diesel Generators: Evaluation of Operating and Expert Experience' August 1987		
R1.5	http://www.diakont.com/technical-blog/increasing-reliability-of-nuclear-reactor-edgs-through-the-use-of-intelligent-digital-control-systems/	*Increasing Reliability of Nuclear Reactor EDGs Through the Use of Intelligent Digital Control Systems*		

Table B.7: Maintenance

Ref. ID	Source Reference	Source Title	Topic	Notes
R2.1	http://ecmweb.com/ops-amp-maintenance/implementing-standby-generator-maintenance-program-diesel-engines	Implementing a Standby Generator Maintenance Program for Diesel Engines	The top three reasons standby generators fail to automatically start or run are: • The generator START switch was left in the OFF position instead of AUTO. • Starting batteries were dead or insufficiently charged. • The fuel filter was clogged due to old or contaminated fuel. Exercise the generator set at least once a month for a minimum of 30 min. loaded to no less than one-third of the nameplate rating. Periods of no-load operation should be held to a minimum because unburned fuel tends to accumulate in the exhaust system.	
R2.2	http://ecmweb.com/ops-amp-maintenance/implementing-	Implementing a Standby Generator Maintenance Program for Diesel	Preventive maintenance for diesel engine generators plays a critical role	

	standby-generator-maintenance-program-diesel-engines	Engines	in maximizing the reliability of DG standby systems	
R2.3	http://www.sbsbattery.com/UserFiles/File/Power%20Qual/PT-7004-Maintenance.pdf	Technical information from Cummins Power Generation	Maintenance is one key to diesel generator set reliability	
R2.4	http://www.munichre.com/site/hsb/get/documents_E1563157526/hsb/assets.hsb.group/Documents/Knowledge%20Center/447%20%20%20Recommended%20Practice%20for%20Maintaining%20Emergency%20and%20Standby%20Engine-Generator%20Sets.pdf	Maintaining Emergency and Standby Engine-Generator Sets	Recommended Best Practices –Maintenance Checklist	
R2.5	http://www.munichre.com/site/hsb/get/documents_E-2049354366/hsb/assets.hsb.group/Documents/Knowledge%20Center/Electrical%20Preventive%20Maintenance.pdf	How to Prevent Costly Electrical System Problems	Preventive Maintenance practices and techniques	
R2.6	http://www.csemag.com/single-article/preventing-generator-failures-with-remote-monitoring/e244c117d97b03cde7a2ae1117ffe4b1.html	Preventing generator failures with remote monitoring	Remote monitoring of typical failure-to-start situations caused by: • Battery, fuel, block heaters, and ignored alarms that lock out the genset. • Heaters and battery chargers exposed to network surges • Charger failure identified through low battery voltage. • Utility voltage dips triggering unnecessary operation of remote Gensets	
R2.7	http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=0ahUKEwjByuDtiM_KAhUJFywKHdeCDV0QFgg5MAA&url=http%3A%2F%2Fdspace.mit.edu%2Fbitstream%2Fhandle%2F1721.1%2F47682%2F42253986-MIT.pdf%3Fsequence%3D2&usg=AFQjCNHcM5_POH9y-RDBmsTwA6wmXWnzYQ	42253986-MIT, Use of Performance-Monitoring to Improve Reliability of Emergency Diesel generators		
R2.8	http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000003002005014	Generator Maintenance Guide for Emergency Diesel Generators,		

Appendix B.4: International Codes and Standards

Table B.8: Standards

Source Title	Date	Source	Topic	Notes
EN 61508 series - Functional safety of electrical/ electronic/programmable electronic safety-related systems	2010		Embedded controller qualification. IEC 61508-1, General requirements; IEC 61508-2, Requirements for electrical/electronic/programmable electronic safety-related systems; IEC 61508-3, Software requirements; IEC 61508-4, Definitions and abbreviations; IEC 61508-5, Examples of methods for the determination of safety integrity levels; IEC 61508-6, Guidelines on the application of IEC 61508-2 and IEC 61508-3; IEC 61508-7, Overview of techniques and measures.	
Electrical Generating Systems Association Standards	Various	http://www.egsa.org/Publications/StandardsDownloadStandards.aspx	Suite of Standards for electrical generators used in the USA; relevant EC&I topics are: • EGSA 100B-1997: Performance Standard for Engine Cranking Batteries Used with Engine Generator Sets • EGSA 100C-1997: Performance Standard for Battery Chargers for Engine Starting Batteries and Control Batteries • EGSA 100D-1992: Performance Standard for Generator Overcurrent Protection, 600 Volts and Below • EGSA 100F-1992: Performance Standard for Engine Protection Systems • EGSA 100E-1992: Performance Standard for Governors on Engine Generator Sets • EGSA 100G-1992: Performance Standard for Generator Set Instrumentation, Control and Auxiliary Equipment • EGSA 100M-1992: Performance Standard for Multiple Engine Generator Set Control Systems • EGSA 100S-1996: Performance Standard for Transfer Switches for Use with Engine Generator Sets • EGSA 100R-1992: Performance Standard for Voltage Regulators Used on Electric Generators • EGSA 107T-1999: Performance Standard for Generator Test Methods (Note: Standard contains 130 test methods.)	
IEC 60623:2001 Secondary cells and batteries containing alkaline or other non-acid electrolytes - Vented nickel-cadmium prismatic rechargeable single cells	2001		Specifies tests and requirements for vented nickel-cadmium prismatic secondary single cells.	
IEC 60896-11:2002 Stationary lead-acid batteries - Part 11: Vented types - General requirements and methods of tests	2002		This part of IEC 60896 is applicable to lead-acid cells and batteries which are designed for service in fixed locations (i.e. not habitually to be moved from place to place) and which are permanently connected to the load and to the d.c. power supply. Batteries operating in such applications are called "stationary batteries". Any type or construction of lead-acid battery may be used for stationary battery applications. This part 11 of the standard is applicable to vented types only. This first edition of IEC 60896-11 cancels and replaces IEC 60896-1 (first edition) published in 1987.	
IEC 60896-21:2004 Stationary lead-acid batteries - Part 21: Valve regulated types - Methods of test	2004		This part of IEC 60896 applies to all stationary lead-acid cells and monobloc batteries of the valve regulated type for float charge applications, (i.e. permanently connected to a load and to a d.c. power supply), in a static location (i.e. not generally intended to be moved from place to place) and incorporated into stationary equipment or installed in battery rooms for use in telecom, uninterruptible power supply (UPS), utility switching, emergency power or similar applications. The objective of this part of IEC 60896 is to specify the methods of test for all types and construction of	

Source Title	Date	Source	Topic	Notes
			valve regulated stationary lead acid cells and monobloc batteries used in standby power applications	
IEC 60896-22:2004 Stationary lead-acid batteries - Part 22: Valve regulated types - Requirements	2004		This part of IEC 60896 applies to all stationary lead-acid cells and monobloc batteries of the valve regulated type for float charge applications, (i.e. permanently connected to a load and to a d.c. power supply), in a static location (i.e. not generally intended to be moved from place to place) and incorporated into stationary equipment or installed in battery rooms for use in telecom, uninterruptible power supply (UPS), utility switching, emergency power or similar applications. The objective of this part of IEC 60896 is to assist the specifier in the understanding of the purpose of each test contained within IEC 60896-21 and provide guidance on a suitable requirement that will result in the battery meeting the needs of a particular industry application and operational condition. This standard is used in conjunction with the common test methods described in IEC 60896-21 and is associated with all types and construction of valve regulated stationary lead-acid cells and monoblocs used in standby power applications.	
IEC 62342:2007 Nuclear power plants - Instrumentation and control systems important to safety - Management of ageing	2007		Provides strategies, technical requirements, and recommendations for the management of ageing of nuclear power plant instrumentation and control systems and associated equipment. Also includes annexes on test methods, procedures, and technologies that may be used to verify proper operation of such equipment and aim to prevent ageing degradation from having any adverse impact on the plant safety, efficiency, or reliability. Applies to all types of nuclear power plants and relates primarily to safety.	
IEC 62465:2010 Nuclear power plants - Instrumentation and control important to safety - Management of ageing of electrical cabling systems	2010		IEC 62465:2010 provides strategies, technical requirements, and recommended practices for the management of normal ageing of cabling systems that are important to safety in nuclear power plants. The main requirements are presented in the body of this International Standard followed by a number of informative annexes with examples of cable testing techniques, procedures, and equipment that are available for the nuclear industry to use to ensure that ageing degradation will not impact plant safety.	
IEC 62671:2013 Nuclear power plants - Instrumentation and control important to safety - Selection and use of industrial digital devices of limited functionality	2013		Addresses certain devices that contain embedded software or electronically-configured digital circuits that have not been produced to other IEC Standards which apply to systems and equipment important to safety in nuclear power plants, but which are candidates for use in nuclear power plants. It provides requirements for the selection and evaluation of such devices where they have dedicated, limited, and specific functionality and limited configurability.	
IEC TS 60034-27:2006 Rotating electrical machines - Part 27: Off-line partial discharge measurements on the stator winding insulation of rotating electrical machines	2006		Provides a common basis for measuring techniques and instruments, the arrangement of test circuits, normalization and testing procedures, noise reduction, the documentation of test results, the interpretation of test results with respect to partial discharge off-line measurements on the stator winding insulation of rotating electrical machines.	
IEC TS 60034-27-2:2012 Rotating electrical machines - Part 27-2: On-line partial discharge measurements on the stator winding insulation of rotating electrical machines	2012		Provides a common basis for: • measuring techniques and instruments; • the arrangement of the installation; • normalization and sensitivity assessment; • measuring procedures; • noise reduction; • the documentation of results; • the interpretation of results with respect to partial discharge on-line measurements on the stator winding insulation of non-converter driven rotating electrical machines with rated voltage of 3 kV and up.	
IEEE 1106-2005 - IEEE Recommended Practice for Installation, Maintenance, Testing, and	2005		This recommended practice provides recommendations for installation design and for installation, maintenance, and testing procedures that can be used to optimize the life and performance of vented nickel-cadmium batteries used in stationary standby applications.	

Source Title	Date	Source	Topic	Notes
Replacement of Vented Nickel-Cadmium Batteries for Stationary Applications				
IEEE 1115-2000 - IEEE Recommended Practice for Sizing Nickel-Cadmium Batteries for Stationary Applications	2000		The sizing of nickel-cadmium batteries used in full float operation for stationary applications is covered in this recommended practice.	
IEEE 1188-2005 - IEEE Recommended Practice for Maintenance, Testing, and Replacement of Valve-Regulated Lead-Acid (VRLA) Batteries for Stationary Applications	2005		This recommended practice is limited to maintenance, test schedules, and testing procedures that can be used to optimize the life and performance of valve-regulated lead-acid (VRLA) batteries for stationary applications. It also provides guidance to determine when batteries should be replaced.	
IEEE 32-1972 - IEEE Standard Requirements, Terminology, and Test Procedures for Neutral Grounding Devices	1972		Applies to devices used for the purpose of controlling the ground current or the potentials to ground of an alternating current system. These devices are: grounding transformers, ground fault neutralisers, resistors, reactors, capacitors, or combinations of these. The standard covers the basis for rating, insulation, temperature limitations, tests, and construction.	
IEEE 387-1995 - IEEE Standard Criteria for Diesel-Generator Units Applied as Standby Power Supplies for Nuclear Power Generating Stations	1995		The criteria for the application and testing of diesel-generator units as Class 1E standby power supplies in nuclear power generating stations is described in this IEEE Standard. The principal design criteria, factory production testing, qualification requirements and site testing are covered.	
IEEE 446-1995 - IEEE Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications (Orange Book)	1995		Addresses the uses, power sources, design, and maintenance of emergency and standby power systems. Chapter 3 is a general discussion of needs for and the configuration of emergency and standby systems. Chapter 9 lists the power needs for specific industries. Chapters 4 and 5 deal with selection of power sources. Chapter 6 provides recommendations for protecting both power sources and switching equipment during fault conditions. Chapter 7 provides recommendations for design of system grounding, and Chapter 10 provides recommendations for designing to reliability objectives. Chapter 8 provides recommended maintenance practices.	
IEEE 450-2010 - IEEE Recommended Practice for Maintenance, Testing, and Replacement of Vented Lead-Acid Batteries for Stationary Applications	2010		Maintenance, test schedules, and testing procedures that can be used to optimize the life and performance of permanently installed, vented lead-acid storage batteries used for standby service are provided. This recommended practice also provides guidance to determine when batteries should be replaced. This recommended practice is applicable to standby service stationary applications where a charger maintains the battery fully charged and supplies the dc loads.	
IEEE 484-2002 - IEEE Recommended Practice for Installation Design and Installation of Vented Lead-Acid Batteries for Stationary Applications	2002		Recommended design practices and procedures for storage, location, mounting, ventilation, instrumentation, preassembly, assembly, and charging of vented lead-acid batteries are provided. Required safety practices are also included.	
IEEE 485-2010 - IEEE Recommended Practice for Sizing Lead-Acid Batteries for Stationary Applications	2010		Methods for defining the direct current (dc) load and for sizing a lead-acid battery to supply that load for stationary battery applications in full-float operations are described in this recommended practice. Some factors relating to cell selection are provided for consideration.	

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