UNITED STATES OF AMERICA
BEFORE THE
FEDERAL ENERGY REGULATORY COMMISSION

Complaint of Michael Mabee and Petition	**)**	
to Order Mandatory Reliability Standards	**)**	**Docket No. EL21-99-000**
for Equipment and Monitoring Systems	**)**	
Marketed from the People's Republic of China	**)**	

MOTION TO INTERVENE AND COMMENT OF THE SECURE THE GRID COALITION

Submitted to FERC on September 15, 2021

Pursuant to Rules 206, 212, and 214 of the Rules of Practice and Procedure[1] of the Federal Energy Regulatory Commission (hereafter "FERC" or "Commission") and the FERC Notice of Complaint in Docket No. EL21-99-000[2], the Secure the Grid Coalition files this Motion to Intervene in support of the Complaint.

MOTION TO INTERVENE

The Secure the Grid Coalition is an ad hoc group of policy, energy, and national security experts, legislators, and industry insiders who are dedicated to strengthening the resilience of America's electrical grid. The Coalition aims to raise awareness about the national and international threat of grid vulnerability, and encourage the steps needed to neutralize it. Our group and its individual members have been frequent participants in FERC dockets related to issues of grid security. We bring a wide variety of expertise in cybersecurity, physical security, public policy and believe our perspective is in the public interest – specifically, the interest of citizens and businesses that depend on the security of the electric grid. Therefore, the Commission should grant the Secure the Grid Coalition's Motion to Intervene as it is in the public interest.

[1] 18 C.F.R. §§ 385.206, 385.212, and 285.214 (2019).
[2] Filed with the Commission on August 26, 2021.

COMMENTS ON COMPLAINT

The Secure the Grid Coalition has conducted a thorough review of the text and exhibits of the Complaint as well as other comments filed on this docket and our members believe that ample evidence exists to justify a Commission-led Technical Conference and/or Special Task Force to oversee a thorough investigation by FERC staff and the designated Electric Reliability Organization (ERO) – the North American Electric Reliability Corporation (NERC), in conjunction with the Nuclear Regulatory Commission (NRC), the National Laboratories, U.S. intelligence agencies, state-level law enforcement agencies and public service commissions, and power grid control system cyber security industry experts to determine the potential threat posed by Chinese transformers and other grid control and monitoring systems and components to *both* the Bulk Electric System (BPS) and the Distribution Grid, and particularly with respect to those portions of the grid that support offsite power to nuclear power generation facilities.

FERC-LED TECHNICAL CONFERENCE AND TASK FORCE TO LEAD INVESTIGATION

We note that in the past the Commission has sometimes used a Technical Conference as a vehicle to sort out issues raised by complaints.[3] The Commission Chairman has the authority to set up such a Technical Conference and we believe the merits of this complaint justify it. However, we believe that the investigation into the threat posed by foreign made grid components – particularly those that could risk the loss of offsite power to nuclear power generation facilities – justifies more than just a conference, but rather a Special Task Force that can draw upon experts from inside and outside of the electric power industry and the federal and state governments.

[3] Notice announcing a technical conference the Commission held in October 2015 regarding complaints about a capacity market rate in MISO surrounding dockets EL15-70-000, EL15-71-000, and EL15-72-000, EL15-82-000. Link: https://www.federalregister.gov/documents/2015/10/08/2015-25632/public-citizen-inc-v-midcontinent-independent-system-operator-inc-the-people-of-the-state-of

THE CONCERN WITH CHINESE GRID COMPONENTS SUPPORTING OFFSITE POWER TO NUCLEAR POWER GENERATORS

It is known that single points of failure can cascade into multiple, additional failures impacting large areas with loss of electric power. It is therefore crucial that the transformers and other essential substation equipment sourced from China be tallied and then investigated by expert teams to determine the possible existence of "loading." It will be necessary to conduct a circuit analysis in order to answer the question:

> "How many transformers or other grid components are "loaded" with an on/off switch capability or does not have process sensor authentication that could cause single or multiple points of failure sufficient to create a cascading failure that would overcome the redundancy of circuitry serving downstream nuclear power plants' offsite 1 and 2 circuits?"

Throughout the 2003 Great Northeastern Blackout, eight operating nuclear generating stations went offline due to cascading failures. The stations were:

Fermi 2 – Newport, Michigan

Oyster Creek – Forked River, New Jersey (decommissioned September, 2018)

Nine Mile 1 – Scriba, New York

Fitzpatrick – Scriba, New York

Nine Mile 2 – Scriba, New York

Ginna – Ontario, New York

Indian Point 2 – Buchanan, New York (permanently shutdown April, 2020)

Indian Point 3 – Buchanan, New York (permanently shutdown April 2020)

All of the above stations tripped due to response to frequency fluctuations or low frequency on the offsite power sources.[4]

If there are enough Chinese-made transformers and/or other grid components that could be maliciously manipulated to cause multiple points of failure sufficient to overcome the redundancy of circuitry serving downstream nuclear power plants' offsite circuits, it could result in these stations losing offsite power. The safety systems supporting the reactor(s) and spent fuel infrastructure(s) would then be reliant on Emergency Diesel Generators (EDGs), which are not fully tested to the extremes of this scenario.

Furthermore, transformer issues in nuclear plants are not hypothetical. A nuclear plant's station auxiliary transformer failed because of a firmware failure in the Load Tap Changer (LTC) control. The hardware backdoors installed in the Chinese-made transformer can be used to cause this type of transformer failure and prevent it from being detected. Transformer LTCs exposed a vulnerability that must be addressed yet is out-of-scope for NERC CIP, NERC Supply Chain, and NRC Reg Guide 5.71/NEI-0809 requirements and not addressed by other industry cyber security guidance.[5]

We recognize that the Commission does *not* have regulatory authority over the nuclear power industry, and we also observe that the nuclear power industry is perhaps one of the safest and also one of the most highly regulated industries in the United States. Regardless, because FERC oversees the BPS, we believe that the Commission has a special duty to ensure that the nuclear power industry does not suffer losses of offsite power that could precipitate the industry having to rely upon EDGs to run onsite safety systems. As can be seen from the example above (and associated source website), these transformer issues have occurred in non-nuclear facilities. Because some of the circuits supporting nuclear power plants are outside the BPS and regulated by state-level commissions, we believe FERC has a duty to coordinate with those

---

[4] Final Report - U.S.-Canada Power System Outage Task Force, August 14th Blackout: Causes and Recommendations

[5] See: https://www.controlglobal.com/blogs/unfettered/the-chinese-hardware-backdoors-can-cause-transformer-failures-through-the-load-tap-changers/

state-level regulators to assist them with making the same assurance to the nuclear power stations in their jurisdictions.

THE CONCERN WITH EMERGENCY DIESEL GENERATORS (EDGs)

Many will proclaim that reliability of EDGs is not a problem. Members of our Secure the Grid Coalition contest this claim. Among them are Dr. Gene Lim who is an authority on nuclear plant technology, new nuclear plant startup operations, emergency shutdown operations, and offsite power and safety systems related to nuclear plant operations. Dr. Lim personally conducted the world's first "live" and "physical" test of EDG performance and reliability in a real "Loss of Offsite and Onsite AC Power" to a nuclear power plant operating at 75% full power in the country of Japan in 1971. Our Coalition includes the following comments from Dr. Lim on the topic of EDGs:

[Beginning of Dr. Lim's Comments]

> The fact remains that there is "no actionable information on the reliability of EDGs and their impact on energy assurance and resiliency."[6] Moreover, fuel shortages for EDGs are not difficult to imagine in a widespread grid-down environment.[7] Additionally, EDGs are not tested to operate for long periods of time. The Clean Air Act regulations limit operations to 200 hours per year for non-emergency use, which would be testing.[8]
>
> As the IEEE standard states, the PREP's "efforts created the most comprehensive facility equipment reliability database in existence." IEEE's earlier reports are identical to the

---

[6] Marqusee, Jeffrey, Sean Ericson, and Don Jenket. 2020. Emergency Diesel Generator Reliability and Installation Energy Security. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5C00-76553. https://www.nrel.gov/docs/fy20osti/76553.pdf . PAGE 1

[7] Ibid, PAGE 2

[8] Ibid, PAGE 8

reliability data reported in the U.S. Army standard (10), which also is derived from the PREP database. The Army has not updated their published guidance since 2006 and now relies on the IEEE documentation of its data collection.

Both government and commercial assessments of reliability are dependent on the recent IEEE reported results. For EDGs, the IEEE- and PREP-reported reliability data is inadequate and inappropriate for assessing the performance of EDGs for providing backup power during a grid outage for three reasons:

1. IEEE and PREP only report annual failure rates, which are not relevant for assessing the run time failure rate of an EDG. EDGs only run during a grid outage or for testing, which accounts for a very small fraction of the year. The annual failure rate is sensitive to the number of times an EDG is run (i.e., the number of opportunities it has to fail), which is dependent on the local grid reliability and the testing schedule.

2. EDGs are turned on and off much more frequently than prime generators. EDGs are not kept on hot standby. Thus, the failure to start and carry load is an important characteristic usually not considered in assessing continuous power systems. The probability of an EDG failing to start and carry the load is a well-recognized failure event, but IEEE and the underlying PREP data do not provide this key reliability statistic.

3. The time to repair reported by IEEE does not include the logistics associated with a repair. It reports only the time required to make the repair once the needed parts and labor are on-site. The time required to obtain parts and have the appropriate technicians on-site is significant and can be larger than the time needed to make the repair.[9]

---

[9] Ibid, PAGES 8,9

It is time to rethink the safety of our nuclear power stations with the shocking revelation of potentially "loaded" transformers manufactured and/or monitored by adverse nations.

U.S. NRC does not allow "live" tests of EDGs because it is "unsafe." If it is unsafe as a testing procedure under laboratory-controlled conditions, when both Offsite Power 1 and 2 are available in the event of a misstep in the testing process, then how can it be relied upon to function safely and reliably during the chaotic immediate situation where both Offsite Power 1 and Offsite Power 2 are unavailable because of grid-down conditions, and emergency power becomes a matter of life and death to millions?"

[End of Dr. Lim's Comments]

INFORMATION RESOURCES JUSTIFYING THE CONCERN WITH (EDGs)

The Secure the Grid Coalition would like to provide the Commission and its staff with information resources that justify the concerns of Dr. Lim and our Coalition and point to the need for a FERC-led Technical Conference and Task Force to lead an investigation into the matter of Chinese-made transformers and grid components, particularly those which could cause a loss of offsite power to nuclear power stations. These are listed, chronologically, in the attached enclosures listed below:

Enclosure 1 - Method of Attacking Nuclear Power Stations Remotely By Dr. Gene Lim – Sept 2021

Enclosure 2 - "Futility At The Utility" by Union of Concerned Scientists – Feb 2007

Enclosure 3 - "NRC Information Notice 2008-05: Fires Involving Emergency Diesel Generator Exhaust Manifolds" – Apr 2008

Enclosure 4 - "NRC Information Notice 2010-04: Diesel Generator Voltage Regulation System Component Due To Latent Manufacturing Defect – Feb 2010"

Enclosure 5 - "NRC Information Notice 2010-23: Malfunctions Of Emergency Diesel Generator Speed Switch Circuits – Nov 2010"

Enclosure 6 - ISL "Emergency Diesel Generator Failure Review 1999 – 2001" – Sept 2011

Enclosure 7 - "Nuclear Power(less) Plants" by Dave Lochbaum – Oct 2015

Enclosure 8 - "USAF Electromagnetic Defense Task Force Report 2.0" – 2019 – See Appendix 1, pages See appendix 1 and 1.1 – pages 53 through 73

Enclosure 9 - "NREL Report on Emergency Diesel Generator Reliability and Installation Energy Security – April 2020"

WILLINGNESS TO ASSIST

The Secure the Grid Coalition welcomes any requests for assistance from the Commission and we would be glad to help identify experts inside and outside of government and industry to help with the proposed Technical Conference and to populate the ranks of the proposed Task Force to conduct the proposed investigation.

Respectfully submitted by,

Thomas J. Waller Jr.

Co-Director

Secure-the-Grid Coalition

twaller@centerforsecuritypolicy.org

Douglas. Ellsworth

Co-Director

Secure-the-Grid Coalition

doug.ellsworth@usapact.org

Method of Attacking Nuclear Power Stations Remotely

– By Dr. Gene Lim

- This PDF has been created by Dr. Gene Lim who is a nuclear reactor core designer and expert on nuclear station operations.
- This PDF provides an overview for how an adversary can attack nuclear power stations remotely by attacking the sources of offsite power and evidence that adversaries are familiar with these attack techniques.
- This PDF underscores why industry cannot rely solely on Emergency Diesel Generators (EDGs) and must protect sources of offsite power to nuclear power stations.

M. Gene Lim, Sc.D. in Applied Nuclear Science

- Operator: The Electric Power Grid Network Analyzer. Purdue Univ. 1959
- Nuclear Reactor Operator (for UVAR): Licensed by the USAEC (1962)
- Nuclear Reactor Core Designer: Westinghouse Nuclear Plants (1965-1968)
- Nuclear Plant Startup Engineer/Physicist/Transient Analyst: Westinghouse Nuclear Plants in the USA and Japan (1969-1975)
- Japan Operations Manager: Westinghouse (1975-1978)
- First American to present Westinghouse Nuclear Plant in China (1979)
- President: Westinghouse Nuclear Korea (1978-1988)
- Council Member: USO Korea Branch (1979-1988)

Nuclear Plant's Ultimate & Severest Test (Training) is called LoOPG Test at Power

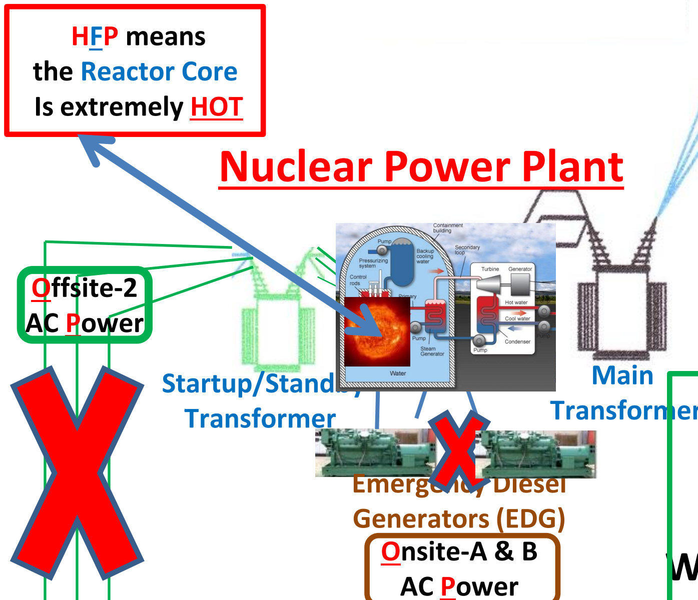
It is equivalent to Military's "Basic Combat Training with Live Bullets"

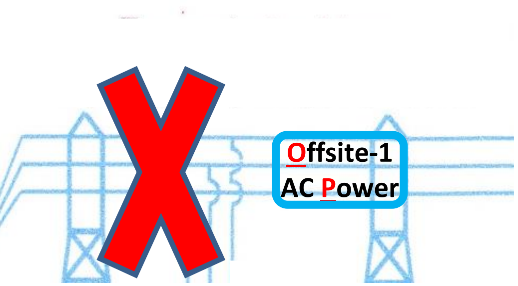
(LoOPG: Loss of Offsite and AC Power Grid)

Neither the US nor South Korean "Nuclear Plant Personnel" are trained with LoOPG Test at Power

1

The object of the LoOP Test
is to confirm
the Emergency Diesel Generators
will Start and Function
in 11 Seconds
Automatically,
the 1st Time, &
Run Continuously
when LoOPG happens





2

Please note:
LoOPG Test at Power
was forbidden by
Westinghouse & USAEC in the U.S
But
It was mandatory in Japan.

KEPCO & I conducted the Test
@75%HFP
at 15:00 hour
November 24, 1970
at Mihama Nuclear Plant .

3

I strongly "Recommend" that
the LoOP Test at HFP (or its equivalent) be "Mandatory" in the U.S.
to train our Nuclear Plant Personnel (physically) for "Combat" and
to instill the "Combat Mentality" in their minds
in the era of our "Fight" with Global Terrorists who
want to destroy our Nuclear Plants in the U.S.
The Emergency Diesel Generators' 39,400 failures are the "Direct Consequences"
of "Not Having" the "Basic Combat Training with Live Ammunition".

Would you approve our Navy SEAL's Basic Underwater-Demolition SEAL Training
without "WATER"?

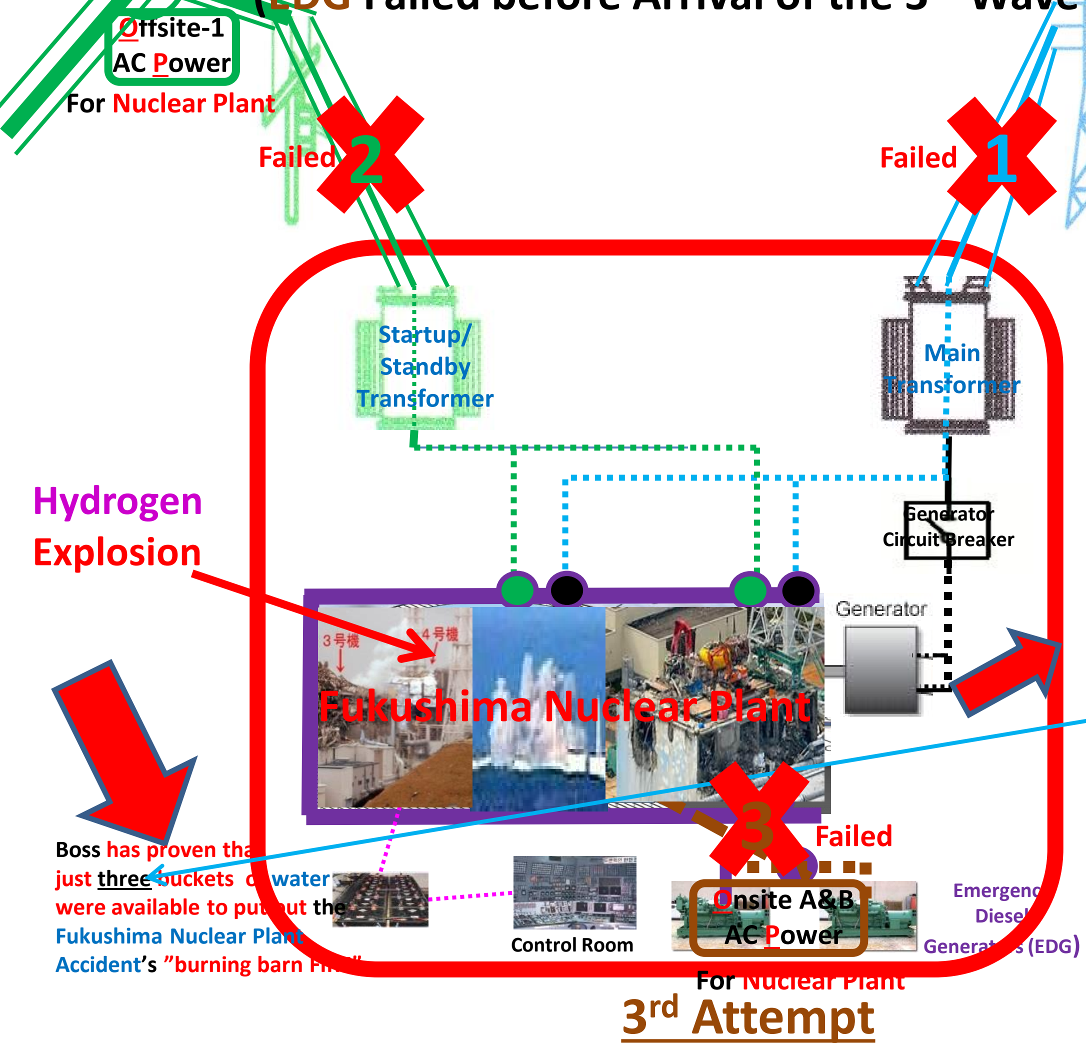
MG Lim

Japan's Fukushima Nuclear Plant's SD-LOOPG Accident

and also

Demonstrated Un-Reliability of Emergency Diesel Generators

(EDG Failed before Arrival of the 3rd Wave of Tsunami which Capsized the EDG)



Fukushima Accident Time Table:

March 11, 2011
- 14:46 Earth Quake
- 14:46 Reactor Scrammed by Earth Quake
- 1 ~14:46 Transmission Lines Disabled
- 2 ~14:46 Sub-Transmission Lines Disabled
- 14:47 EDGs Auto Started ?? (Being contested !!)
- 14:52 IC (A&B) Started (once)
- 15:03 IC (A&B) Stopped
- 15:17 IC (A) Restarted (twice)
- 15:19 IC (A) Stopped
- 15:32 IC (A) Restarted (thrice)
- 15:34 IC (A) Stopped

BoSS to backup EDG

By Japan CNIC & Attorney Itoh

- 3 15:37 EDGs Disabled by Tsunami ?? (Being contested
  CNIC said EDGs failed before Tsunami arrival
- 15:42 Arrival of the 3rd & damaging wave of Tsunami !!!

March 12, 2011
- 15:36 Hydrogen Explosion @ Unit 1

March 14, 2011
- 11:01 Hydrogen Explosion @ Unit 3

March 15, 201
- 06:00 Possible Hydrogen Explosion @ Unit 2

MG Lim

Japanese News Media Articles on Testimonies of North Korea Defectors

The Testimony of Former North Korea Military Executive

北が対日原発自爆テロを計画、訓練も　韓国侵攻前「戦意そぐ」元軍幹部証言

【韓国】

北朝鮮の朝鮮人民軍が対韓国開戦直前に日本全国にある原子力発電所施設に特殊工作員計約６００人を送り込み、米軍施設と同時に自爆テロを起こす計画を策定していたことが２８日、軍元幹部ら脱北した複数の関係者の証言で分かった。計画実施に向け工作員を日本に侵入させ、施設の情報収集を重ね、日本近海でひそかに訓練も行っていたという。北朝鮮による原発テロが現実的脅威に浮上した。

元幹部らによると、計画は、金日成（キム・イルソン）主席の後継者だった金正日（ジョンイル）総書記が「唯一指導体系」として朝鮮労働党と軍及び工作機関に対する指示系統を掌握した１９７０年代半ば以降、具体化に動き出し、９ 格化したという。

計画には、大別して２つの特殊部隊が編成された。「対南（韓国）」 で、それぞれ２個大隊約６００人ずつが充てられた。 チームが組まれ、対南侵攻直前に日本と韓国に上陸。それぞれ連携して 基地や原発のほか、東京などの重要施設を自爆テロで同時爆破する作戦

原発は福井や新潟など日本海側に加え、太平洋側の施設も自爆テロの対象とされた。

作戦のため、現地の協力者らが施設周辺を撮影するなどし毎年、情報を更新。特殊工作員が潜水艇で日本に上陸、施設内に忍び込んで情報収集することもあったという。

情報を基に施設を忠実に再現した模型が作られ、机上演習が重ねられた。

脱北した別の朝鮮労働党工作機関関係者によると、特殊部隊が潜水艇で日本近海に繰り出し、実戦に向けた訓練も行われた。９４年には、日本近海で行った自爆テロ訓練中の事故で死亡し、北朝鮮で最大の栄誉とされる「共和国英雄」の称号を得た工作員もいたという。

北朝鮮による対南侵攻にとって最大の脅威は沖縄などに駐留する米軍だ。元幹部によると、日本全体を米軍を支える「補給基地」とみなし、米軍に先制するため、開戦前の対南テロに加え、対日同時テロが策定されたという。

原発が最重要ターゲットとされたのは、爆破すれば、「甚大な損害を与えられ、核兵器を使う必要がなくなる」（元幹部）との思惑からだという。さらには、広域に放射能が拡散することで「日韓両国民の間に戦争に反対する厭戦（えんせん）ムードが広がり、日米韓の戦意をそぐ政治的効果を狙った」と元幹部は説明した。

【対日原発テロ計画】

金総書記「日本を人が住めないようにしろ」

【北朝鮮】

北朝鮮の朝鮮人民軍元幹部らの証言で新たに判明した原発同時自爆テロ計画は、金正日（キムジョンイル）総書記の指示下に策定されたとされ、金総書記は「決死隊の同時攻撃で日本に人が住めないようにしろ」とも命じていたという。元幹部によると、潜水艇による日本への侵入も繰り返され、「日本への浸透はたやすかった」とも。テロの脅威を前に原発警備のあり方が問われている。

元幹部らによると、北朝鮮は日本の商業原発稼働前から関心を持ち、「１９６０年代 対象として注目していた」という。

進める北朝鮮だが、ミサイルに搭載する核弾頭の軽量化には至っていないと れに比べ自爆テロは「核兵器を使うより威力がある」手っ取り早い手段とみ

で死亡しても家族に任務が知らされることはなく、国民をコマとしか扱わない北朝鮮の非道さが改めて浮かぶ。

計画を後押ししたのは、９０年ごろから開発が進んだ潜水艇と、特殊潜水艦の存在だ。「発見されずに上陸でき、情報収集のための工作員浸透も９０年代に最も頻繁に行われた」（元幹部）

北朝鮮の基地にいた工作員が情報収集の任務を終え、翌日には戻っているといったことも。「日本にはスパイを取り締まる法律もないと聞かされており、日本上陸時は銃も携帯しなかった。韓国に比べ浸透は非常にたやすかった」

東日本大震災で原発の弱さが露呈し、警察庁などが今月１１日に東京電力福島第２原発でテロを想定した合同訓練を行うなど、日本でもテロ対策が見直され始めた。ただ、長大な海岸線を抱え、工作員侵入を水際で防ぐにも限界がある。

元幹部によると、北朝鮮も計画の再考を迫られた。９６年９月に韓国の江陵（カンヌン）市で北朝鮮の潜水艦が座礁し、工作員ら２６人が韓国側と銃撃戦を繰り広げた。それ以降は浸透の頻度は低下したが、潜水艇による侵入はその後も続けられたという。

「北朝鮮が対南侵攻の意志を捨てることはなく、金正恩（ジョンウン）政権になってもテロ計画は生き続けている」。元幹部はこう警告する。

The Testimony of Former North Korea Military Executive

①

北が対日原発自爆テロを計画、訓練も 韓国侵攻前「戦意そぐ」元軍幹部証言

情報を基に施設を忠実に再現した模型が作られ、机上演習が重ねられた。

脱北した別の朝鮮労働党工作機関関係者によると、特殊部隊が潜水艇で日本近海に繰り出し、実戦に向けた訓練も行われた。94年には、日本近海で行った自爆テロ訓練中の事故で死亡し、北朝鮮で最大の栄誉とされる「共和国英雄」の称号を得た工作員もいたという。

北朝鮮による対南侵攻にとって最大の脅威は沖縄などに駐留する米軍だ。元幹部によると、②日本全体を米軍を支える「補給基地」とみなし、米軍に先制するため、開戦前の対南テロに加え、対日同時テロが策定されたという。

③原発が最重要ターゲットとされたのは④爆破すれば、「甚大な損害を与えられ、⑤核兵器を使う必要がなくなる」（元幹部）との思惑からだという。さらには、広域に放射能が拡散することで「日韓両国民の間に戦争に反対する厭戦（えんせん）ムードが広がり、日米韓の戦意をそぐ政治的効果を狙った」と元幹部は説明した。

The Key Points of the Testimony are

① ② ③ ④ ⑤

① 北が対日原発自爆テロを計画、訓練も 韓国侵攻前「戦意そぐ」元軍幹部証言

② 日本全体を米軍を支える「補給基地」とみなし、米軍に先制するため、開戦前の対南テロに加え、対日同時テロが策定されたという

③ 原発が最重要ターゲットとされたのは、

④ 爆破すれば、「甚大な損害を与えられ、

⑤ 核兵器を使う必要がなくなる」

Interpretation of ① ② ③ ④ ⑤

①
北が対日原発自爆テロを計画、訓練も 韓国侵攻前「戦意そぐ」元軍幹部証言

North Korea's Training and Plans for suicidal terrorism on Japanese Nuclear Plants are to heighten War Spirit before attacking South Korea

②
日本全体を米軍を支える「補給基地」とみなし、米軍に先制するため、開戦前の対南テロに加え、対日同時テロが策定されたという

We consider entire Japan as U.S. Military Supply Base to support South Korea. Therefore the simultaneous terrorism on Japan and South is to be implemented to have Preemptive Control of U.S. Troop movement in Japan

③
原発が最重要ターゲットとされたのは

The Nuclear plants are selected as the most important targets, because

④
爆破すれば、「甚大な損害を与えられ、

when they explode, they cause monumental damages

⑤
核兵器を使う必要がなくなる」

It is not necessary to use the Nuclear Weapons

Mr. Wakasugi's book depicts

North Korea trained Korean-Chinese, Mr. Choi, perpetrates S-LOOPG accident/attack on Nuclear Plant by destroying the Electric Power Grid Towers.

All the *lessons* learned from the Fukushima Nuclear Plant accident and all the *countermeasures* *to prevent such accident Can Not Protect Nuclear Plants and Can Not Prevent the S-LOOPG accident/attack!*

The worse than the Fukushima Nuclear Accident (SD-LOOPG accident) is perpetrated by

destroying the Electric Power Grid Towers

and

failed Emergency Diesel Generators for Nuclear Plant

The destruction is carried out by Mr. Choi/his Japanese collaborators with improvised dynamite

Mr. Choi worked for *pro-North Korea* Chong-ryon [총련, 總聯 or 朝鮮総連] in Japan

FUTILITY
AT THE
UTILITY

How use of the wrong answer key for safety tests went undetected for 20 years at Fermi Unit 2

It was only fortuitous that no safety problems resulted from the operation of Fermi with inaccurate technical specifications.
NRC Senior Manager, February 1990

Fermi would operate for at least sixteen more years with inaccurate technical specifications.

Union of Concerned Scientists
Citizens and Scientists for Environmental Solutions

DAVID LOCHBAUM
DIRECTOR, NUCLEAR SAFETY PROJECT
FEBRUARY 2007

FUTILITY AT THE UTILITY

INTRODUCTION

For over two decades, workers at Detroit Edison's Fermi Unit 2 nuclear power reactor dutifully tested a key safety system—the one that reacts to interruptions in electricity and signals the onsite emergency diesel generators to start and power components that protect the reactor core from damage. The proper functioning of the emergency diesel generators is extremely important. As a measure of that importance, when the emergency diesel generators become disabled, Fermi Unit 2 must be shut down within 12 hours to avoid causing a breakdown at the plant that would expose the public to undue risk.

But over those two decades, workers tested this crucial safety system using the wrong answer key. As a result, although the safety system was repeatedly given a passing grade, the test did not, in actuality, gauge whether the system would have worked properly in case of emergency. Twenty years of testing resulted in a safety system that may never have been adequate.

Hard to believe? Certainly. More unbelievable is the fact that Detroit Edison and the Nuclear Regulatory Commission (NRC) had hundreds, perhaps thousands, of opportunities to discover this problem during those decades. Lots of people had lots of chances to notice the discrepancy. It wasn't that one person made many mistakes or many people made the same mistake. Many people made many mistakes for many years.

How could this happen? The failure to ask and answer this simple question just once is the primary reason the problem was missed by so many for so long. When other problems were uncovered – as frequently happened over the years – no one asked how the problems had gone unnoticed. Consequently, the process flaws that initially created the problem and then allowed them to remain undetected were not identified and fixed. Instead, individual problems were remedied only when they surfaced, while the uncorrected process flaws continued to create new problems and sustain old ones.

This report documents our inquiry into the 20-year period during which Detroit Edison tested the emergency diesel generator protection safety system using the wrong answer key. The first section explains how the emergency diesel generator protection system functions and how the discrepancy was introduced in August 1986. The next section, along with the timeline provided in the appendix, chronicles the numerous opportunities Detroit Edison and the NRC had to uncover the discrepancy prior to its finally being revealed in August 2006. The final section describes steps the NRC must take to rectify the mistakes made in incorrectly testing emergency equipment, as well as strategies for detecting and correcting such glaring errors in the future. This report offers an invaluable, long-overdue lesson for safe operation of Fermi Unit 2 and more than 100 other nuclear power reactors in the United States.

ELECTRICAL BUS VOLTAGE PROTECTION

Nuclear power plants have a single purpose – to generate electricity for sale to residential and commercial consumers. Nuclear power plants themselves consume large amounts of electricity to run the many pumps, fans, hoists, compressors, valves, lights, heaters and other plant components. Most of these components support day-to-day operation of the nuclear plant, but some of the components are the emergency elements needed either to prevent or mitigate reactor accidents. All of the components are normally powered by the electricity generated by the nuclear plant or by electricity drawn from the electrical grid. When a nuclear plant is shut down and the electrical grid becomes unavailable, most components at the plant are rendered useless due to lack of power. Emergency backup power is required by federal regulations at all nuclear power plants so safety equipment can function independent of the grid and plant.

The emergency backup power system for Fermi Unit 2 features four emergency diesel generators (EDGs) configured such that two (EDG-11 and EDG-12) supply power to one division of safety equipment and two (EDG-13 and EDG-14) supply power to a fully redundant second division of safety equipment.

FUTILITY AT THE UTILITY

Figure 1 provides a schematic diagram for one of the two safety-related divisions at Fermi Unit 2. The top portion of the diagram shows the plant's switchyard with the transmission lines connecting the plant to the electrical grid (i.e., the Luzon and Custer lines) along with some of the electrical distribution system for non-essential plant equipment (e.g., Transformer S566 provides electricity to the circulating water (CW) system pumps and equipment). Emergency diesel generators (EDGs) 11 and 12 are shown at the bottom of the diagram providing power to safety-related 4.16 kilovolt electrical buses 11EA and 12EB which in turn supply power to safety-related 480 volt electrical buses 72EA, 72EB, and motor-control centers (MCCs). MCCs are the nuclear plant equivalent to fuse panels in homes: they contain electrical breakers that control power supply to electrical circuits throughout the plant. Non-safety-related 4.16 kilovolt electrical buses 64B and 64C in the middle of the diagram show how the safety-related buses are normally powered from the electrical grid.

Except during periodic tests, the emergency diesel generators are normally not running. They remain in standby mode. Two conditions that signal an emergency diesel generator to start automatically are (1) loss of voltage on its associated electrical bus and (2) undervoltage on that bus. "Loss of voltage" and "undervoltage" sound alike, but they describe two different situations. Figure 2 illustrates the difference. Safety-related electrical buses 11EA and 12EB normally operate at 4.16 kilovolts or 4160 volts. The condition that signals "loss of voltage" for these two electrical buses is voltage falling to or below 3033 volts for more than 2 seconds (this voltage level is called the "setpoint"). "Undervoltage" refers to the voltage falling to or below a setpoint of 3952 volts for more than 44 seconds. The following cases explain how the electrical bus voltage protection is supposed to work.

> Case 1 – Electrical transient with no EDG response: The electrical bus voltage drops below the degraded voltage setpoint of 3952 volts, starting the 44-second timer. But because the voltage returns to over 3952 volts in less than 44 seconds, no signal to start the emergency diesel generator occurs.
>
> Case 2 – Electrical transient with EDG response on degraded voltage: The electrical bus voltage drops below the degraded voltage setpoint of 3952 volts, starting the 44-second time. With voltage still below 3952 seconds after 44 seconds, the emergency diesel generator is signaled to start. Power from the running emergency diesel generator restores the electrical bus voltage to its normal value.
>
> Case 3 – Electrical transient with EDG response on loss of voltage: The electrical bus voltage drops below the loss of voltage setpoint of 3033 volts, starting the 2-second timer. With voltage still below 3033 volts after 2 seconds, the emergency diesel generator is signaled to start. Power from the running emergency diesel generator restores the electrical bus voltage to its normal value.

The time delays and staggered setpoints prevent unnecessary demands on the emergency diesel generators. The 2-second delay for loss of voltage allows momentary "glitches" to be accommodated as power supplies for electrical buses are switched from primary to secondary feeds. Likewise, the 44-second delay for undervoltage allows voltage "droop" as large motors supplied from electrical buses are started. Engineering calculations and analyses support the setpoints and time delays to provide reasonable assurance that the components powered from the electrical buses will function when needed to prevent damage to the reactor core.

On July 2, 1986, Detroit Edison applied to the NRC for an amendment to the Fermi Unit 2 technical specifications that would increase the degraded voltage setpoint for the Division 1 4160-volt electrical bus from 3702 volts to 3952 volts. This increase represented a more stringent safety requirement than in the past. The company justified the change based on the need to correct an original design deficiency and to protect against component damage. The degraded voltage setpoint is established by determining the minimum voltage required for each component supplied by an electrical bus. That minimum voltage varies from component to component. For analogy, consider battery-powered devices. Old batteries may still retain enough juice to illuminate a flashlight or power a portable CD player, but lack enough power to operate a cordless drill. If all these devices were deemed vital, the equivalent of the degraded voltage setpoint for batteries would replace them before their capability dropped below the level needed to operate the cordless drill even though they could still work in a flashlight.

On August 22, 1986, the NRC issued Amendment 4 to the Fermi Unit 2 technical specifications, revising the degraded voltage setpoint for the Division 1 electrical bus to 3952 volts. The NRC granted this change, which Detroit Edison had requested six weeks earlier, since Detroit Edison determined that a degraded voltage setpoint of 3702 volts did not adequately protect components that were powered from the Division 1 electrical bus from damage. But Detroit Edison failed to revise the test procedure for the system—it continued to test for a degraded voltage setpoint of 3702 volts. In other words, if workers determined the setpoint to be greater than or equal to 3702 volts, the test passed. But if the setpoint was less than 3952 volts, the technical specification requirement would not have been met.

So Detroit Edison raised the voltage standards at Fermi, arguing it was important in order to ensure safety. But workers continued to test against the old, lower standard.

On August 25, 2006 – 7,308 days after Amendment 4 was issued – an NRC inspector questioned Detroit Edison on why the degraded voltage test acceptance criterion did not match the requirement in the technical specifications.

For the intervening 20 years, the answer key would have accepted a degraded voltage setpoint of 3702 to 3951 volts – a value Detroit Edison and NRC deemed insufficient to protect safety equipment from damage.

FUTILITY AT THE UTILITY

"Futility at the Utility" is more than a catchy title. It explains how so many people at Detroit Edison and the NRC could have overlooked a simple fact: the technical specifications for one of the most safety-significant components in the plant specified that the Division 1 degraded voltage setpoint was 3952 volts while the actual testing procedures instead checked for a value of only 3702 volts.

For two decades, workers conducted and the NRC-monitored tests for the Division 1 degraded voltage protection that used the wrong answer key. These tests were performed at least once every 18 months,[1] so there were at least a dozen opportunities for someone to notice that passing the test did not equate to satisfying the technical specification requirements. Yet the futility is far deeper. There were literally hundreds, perhaps thousands, of opportunities for the glaring error to be identified. For example, Detroit Edison had to shut down Fermi Unit 2 in February 1988 after discovering it had not been testing the degraded voltage protection system for the emergency diesel generators as required by the technical specifications. The remedies for that problem did not identify other degraded voltage testing problems – although they clearly should have done so. For all that looking, there was no seeing. The timeline provided in the appendix to this report chronicles many missed opportunities to have identified the erroneous testing criterion.

It is truly hard to explain how so many opportunities in a two-decade span could have been missed. If it had been a snake, it would have died of old age. Every time the testing procedure was revised, several people reviewed it. Every time a new system engineer took over responsibility for the emergency diesel generators, his or her turnover process required a review of applicable technical specifications and testing procedures. Every time a training class of new operator candidates reviewed technical specifications and associated testing procedures, they covered the function of the undervoltage protection system. Every time quality assurance auditors verified that testing procedures satisfied regulatory requirements, they had chances to notice the discrepancy. But these people all failed to detect a glaring mistake despite countless opportunities to do so during the two decades.

It wasn't the case of one person making the same mistake over and over or many people making the same mistake. Many people made many different mistakes for many years.

HOW?

The repeated failure of Detroit Edison and NRC to ask and answer this question allowed nonsense like performing tests with the wrong answer key to go unnoticed for two decades. The appendix contains dozens of accounts of Detroit Edison committing egregious errors. Each time, Detroit Edison promised various steps to prevent recurrence. Each time, NRC gave its blessing after varying degrees of scolding..

If nothing else, this latest episode clearly reveals the futility of promising and accepting reforms without first identifying the root cause of a problem. Having failed again and again to pinpoint the cause of its problems, Detroit Edison merely treated the symptoms. And the NRC mistook flailing for fixing.

Picture for a moment an assembly line for automobiles, maybe even one of those in Detroit. An NRC inspector at the end of the line spot checks an automobile selected at random and discovers that its doors open inward instead of outward. The NRC inspector brings it to the attention of the foreman and patiently watches as workers correct the problem. Then there are handshakes and backslaps all around as everyone celebrates finding and fixing the problem. But more than likely, the assembly line will continue to turn out automobiles with improperly installed doors because the NRC inspector, foreman, and workers merely dealt with the consequences at the end of the line rather than addressing the problem at its root.

The assembly line at Fermi Unit 2 keeps turning out surveillance tests that fail to adequately verify compliance with technical specification requirements. The appendix is replete with examples of such failures, yet it is an abridged listing which demonstrates that instead of determining what's wrong with the assembly line and correcting that process flaw, Detroit Edison merely fixes the occasional errant test when someone stumbles across it.

The NRC must compel Detroit Edison to investigate its flawed assembly line. Then and only then can Detroit Edison implement the fixes needed to not only correct yesterday's mistakes but also avoid tomorrow's mistakes. For example, the company claimed that it completed a "*100% verification of the Technical Specification requirements*"[2] in August 1986. It would be extremely useful to understand how a 100% verification failed to notice the multiple non-compliances with technical specification requirements identified after August 1986. Likewise, Detroit Edison shut down Fermi Unit 2 in February 1988 because it had not been testing the degraded voltage protection for the emergency diesel generators as required by technical specifications, allegedly fixed the problem, and restarted the reactor. It would be equally useful to understand how that exercise failed to reveal it was testing the degraded voltage protection for the emergency diesel generators using long outdated technical specification values. In October 1994, Detroit Edison informed the NRC that the failure it had identified earlier that year in not testing the permissive interlocks for the undervoltage protection system as required by technical specifications was widespread, and the company committed to reviewing all other applicable testing procedures. It would be useful to understand how that effort was for naught.

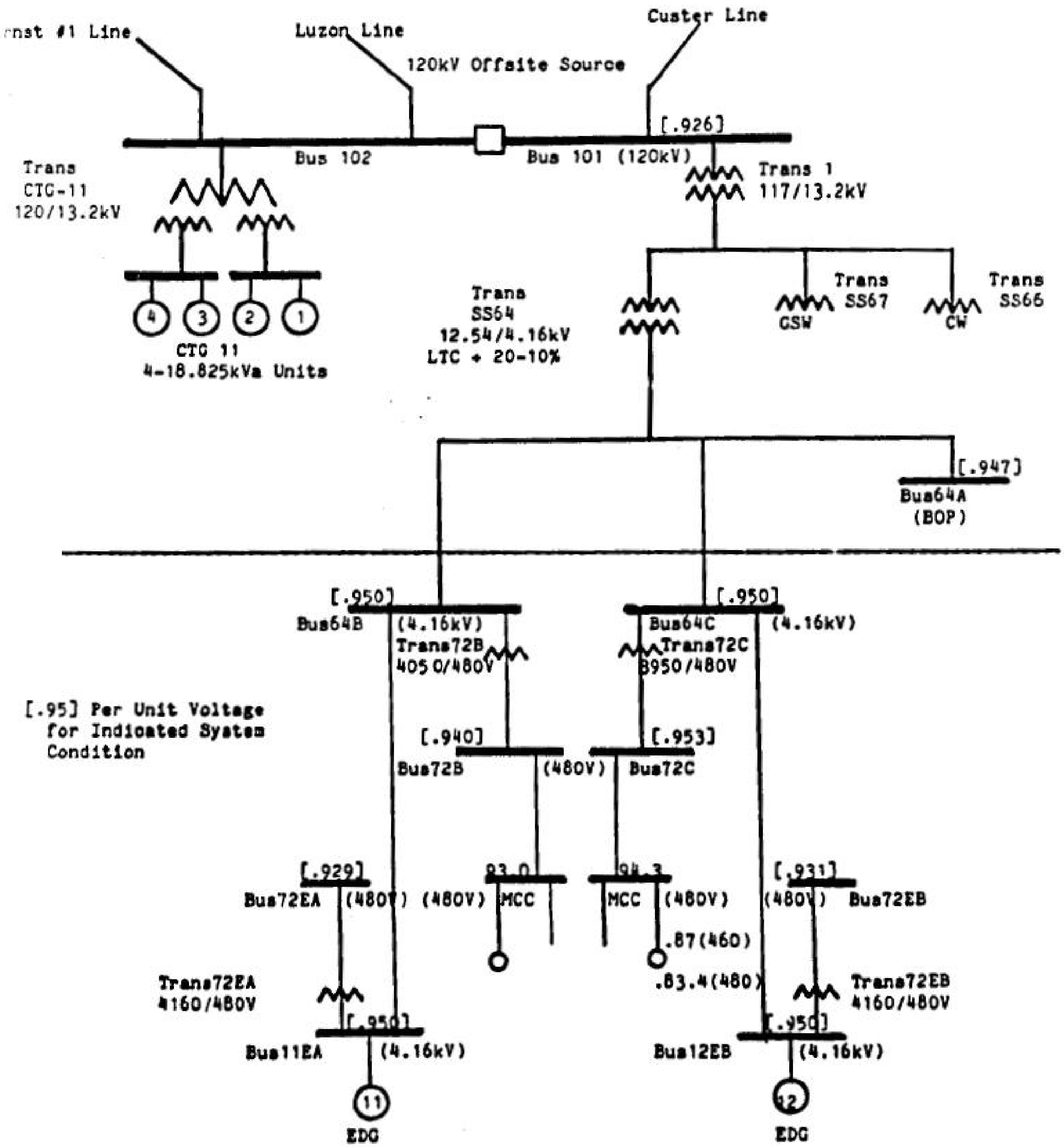
What did the NRC do when the 20-year old testing problem was finally discovered? It "sanctioned" Detroit Edison with a GREEN finding – the lowest severity level in NRC's four-level, color-coded sanction system – for the violation of federal safety regulations spanning two decades. That's all.

Detroit Edison doesn't have to explain how it missed this glaring mistake many times for many years. Detroit Edison doesn't have to fix the many flawed processes that allowed so many of its workers to perform tests with the wrong answer key. This may not be the most useless sanction in nuclear history, but it's likely in the top five.

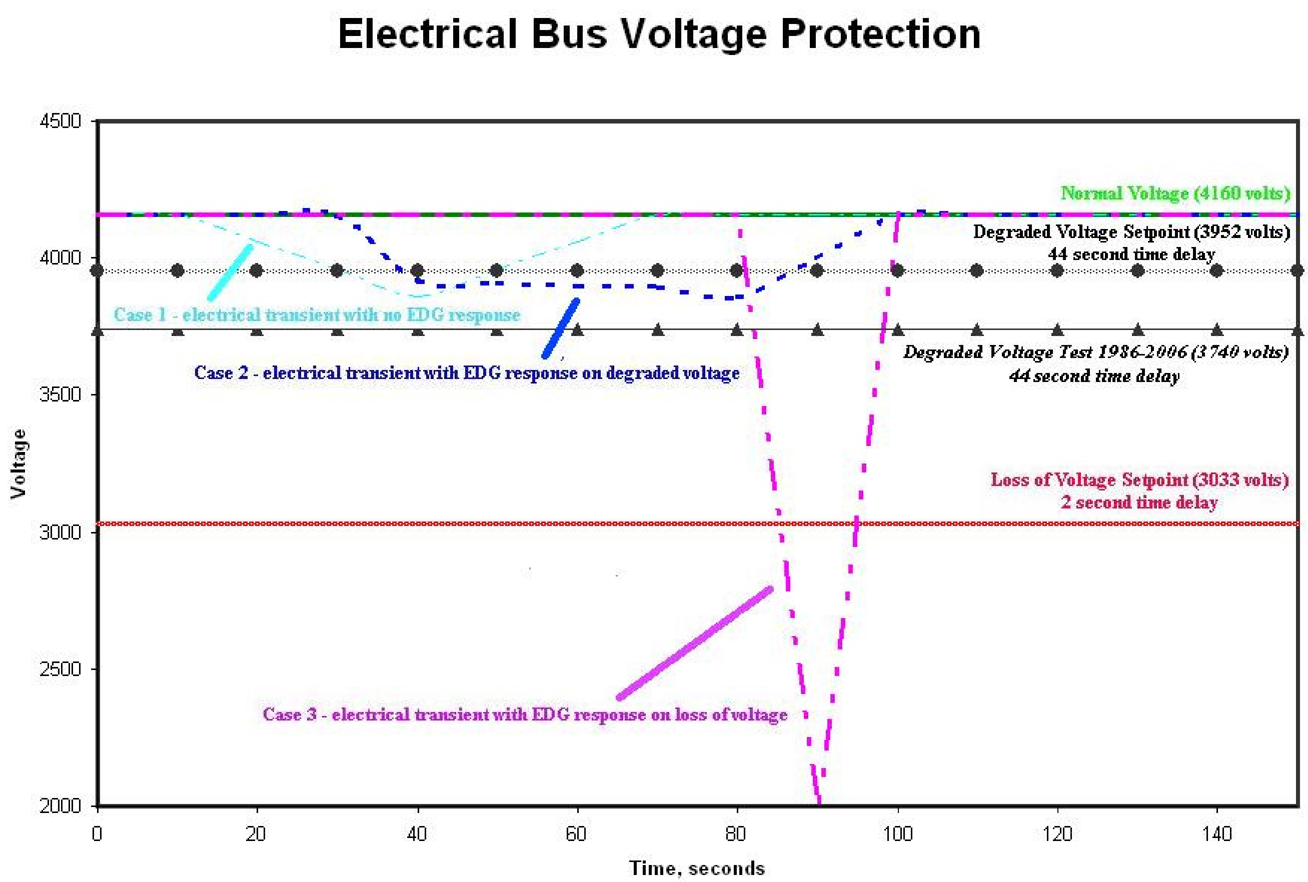
What should the NRC do? By letter dated February 7, 1997, Detroit Edison formally responded to the NRC's query about availability and adequacy of design basis information. Detroit Edison listed many activities conducted over the years at Fermi Unit 2 that provided the company assurance the reactor complied with requirements. All of those activities failed to note that Detroit Edison was testing the Division 1 degraded voltage protection system using the wrong answer key. The NRC should require that Detroit Edison revisit its February 1997 submittal activity-by-activity and explicitly state how each activity failed to catch this problem. The NRC should then require that Detroit Edison state what it had done to remedy the deficiencies identified in each activity. Following some appropriate time span (say, 60 days), the NRC should conduct an audit at Fermi Unit 2 to determine if Detroit Edison has actually completed the remedial actions it identified.

Will the NRC take these steps? Probably not. But an effective regulator would.

Schematic Diagram-Div I



Degraded Grid Setpoint-Maximum Bus Loads-Post Start of Two RHR and Two CS Pumps


Electrical Bus Voltage Protection
4500
4000
3500
3000
2500
2000
Voltage
0
20
40
60
80
100
120
140
Time, seconds
Normal Voltage (4160 volts)
Degraded Voltage Setpoint (3952 volts)
44 second time delay
Case 1 - electrical transient with no EDG response
Case 2 - electrical transient with EDG response on degraded voltage
Degraded Voltage Test 1986-2006 (3740 volts)
44 second time delay
Loss of Voltage Setpoint (3033 volts)
2 second time delay
Case 3 - electrical transient with EDG response on loss of voltage

APPENDIX 1: TIMELINE

Date	Event
August 4, 1984	Workers modified the sight glass used to indicate the oil level for one of the bearings on Emergency Diesel Generator 14. Due to an error, the sight glass was unintentionally and unknowingly installed nearly one inch below its original level.[3] This error went undetected and uncorrected for nearly 17 years and caused catastrophic failure of the bearing on March 21, 1991.
November 26, 1984	The Detroit Edison Company's Vice President for Nuclear Operations certified to the NRC in writing that the Technical Specifications for Fermi Unit 2 were adequate and consistent with the Final Safety Analysis Report and as-built plant design.[4] The NRC relied upon this certification in granting Detroit Edison an Operating License for Fermi Unit 2.
July 1, 1985	According to the NRC: *… a reactor operator (the Nuclear Supervising Operator at the control panel), about an hour into his shift, while withdrawing control rods to achieve criticality on his first attempt ever to bring a commercial power reactor critical, pulled 11 rods in Group 3 to the fully withdrawn position (position 48), rather than position 04 required by the rod pull sheet. This resulted in the reactor prematurely reaching criticality although this was not fully recognized by the licensee until several days later. While pulling the 11th control rod in Group 3, the Short Period Alarm annunciated five times and the pen for the Channel A Source Range Monitor failed to ink for about three minutes. When the pen began inking again the count rate was increasing. At about the same time, the rod pull error was recognized and the reactor operator began reinserting the 11 rods. The Nuclear Shift Supervisor (NSS), was called and came out of his office to consult with the reactor operator. The NSS, who was also responsible for directing his first startup of a commercial power reactor, reviewed the event with the reactor operator and the Shift Technical Advisor in training and determined that the reactor had not gone critical. … A Shift Reactor Engineer made the determination on July 4, 1985, that the reactor had been critical on July 1, 1985, with a 114 second period, and informed his management.*[5]
July 15, 1985	The NRC issued Detroit Edison an Operating License for Fermi Unit 2: *The Nuclear Regulatory Commission (the Commission) has found that:* *…. There is reasonable assurance (i) that the activities authorized by this operating license can be conducted without endangering the health and safety of the public, and (ii) that such activities will be conducted in compliance with the Commission's regulations."*[6]
December 17, 1985	Emergency Diesel Generator 13 failed to start during a surveillance test, the second start failure of EDG 13 since the operating license was issued.[7]

APPENDIX 1: TIMELINE

Date	Event
June 1986	The Independent Safety Engineering Group [an internal audit organization mandated by the NRC as one of the many lessons learned from the Three Mile Island Unit 2 accident] initiated a review of the Technical Specification Surveillance Program. In parallel, the Nuclear Quality Assurance organization audited the Technical Specification Surveillance Testing Program.[8]
July 2, 1986	Detroit Edison submitted a request to the NRC seeking to amend the Fermi Unit 2 operating license to revise the Technical Specification values for degraded grid undervoltage relay setpoints on the Division 1 electrical system. The requested change sought to increase the undervoltage setpoint, from 89 percent to 95 percent of nominal voltage to account for design deficiencies and to allow for Division 1 operability.[9]
July 3, 1986	The NRC imposed a $300,000 fine on Detroit Edison for violations stemming from the July 1, 1985, inadvertent, unrecognized reactor criticality at Fermi.[10] **UCS View: *This fine represented little more than regulatory sabre-rattling by the NRC. The NRC issued Detroit Edison an operating license for Fermi Unit 2 on July 15, 1986 – two weeks AFTER the inadvertent, unrecognized reactor criticality event. Had NRC truly been concerned by the event or Detroit Edison's behavior, it would not have given the company the keys so soon after the event. But a six-figure fine provides the public with the allusion of an aggressive regulator.***
July 8, 1986	Emergency Diesel Generator 14 failed to start during a surveillance test. It was the first start failure of EDG 14 since the issuance of the operating license.[11]
July 9, 1986	Emergency Diesel Generator 14 failed to start during a surveillance test. It was the second start failure of EDG 14 since the issuance of the operating license.[12]
August 1986	The review of the Technical Specification Surveillance Program by the Independent Safety Engineering Group (ISEG) and the audit of the Technical Specification Surveillance Testing Program by the Nuclear Quality Assurance organization concluded. Five items where inadequate surveillance procedures had resulted in equipment or services being rendered technically inoperable were identified.[13] In February 1997, Detroit Edison would emphasize the value of the ISEG review in writing to the NRC: *This activity occurred during the initial operating period of the Fermi 2 plant. Because it represented a 100% verification of the Technical Surveillance Requirements at that time, and because deficiencies were resolved, it was extremely important in establishing a baseline for the procedural control of Technical Specification surveillances.*[14]

APPENDIX 1: TIMELINE

Date	Event
	UCS View: Detroit Edison claimed to have conducted a "100% verification of the Technical Surveillance Requirements" in summer 1986, yet subsequent testing inadequacies were reported in May 1987, October 1987, February 1988, July 1994, and October 1994. The purported "100% verification" had very little value.
August 6, 1986	In a licensee event report (LER) submitted to the NRC by Detroit Edison about its failures to meet the surveillance testing requirements contained in the Fermi 2 technical specifications, the company stated: *Part of Detroit Edison's corrective action to a violation involving not meeting Technical Specification Limiting Conditions for Operation was to review the Fermi 2 Surveillance Program. The review consists of verifying that Technical Specification surveillance requirements are included in appropriate procedures, that they are adequately scheduled, and for selected surveillance procedures to verify that the surveillance requirements are adequately implemented. While performing this review, five cases have been found where a surveillance requirement was not specifically addressed in a procedure, or that documentation of performing a surveillance is not available because it was not specifically required by procedure.*[15]
August 8, 1986	In issuing Detroit Edison an operating license for Fermi Unit 2 on July 15, 1985, the NRC made the license conditional on the company implementing a testing regime for the lubricating oil used in the emergency diesel generators. [16] On this date, workers identified that lube oil filter checks for the emergency diesel generators had not been performed during the previous three months as required.[17]
August 22, 1986	The NRC issued amendment 4 to the Fermi 2 operating license and approved revisions to the technical specifications that increased the Division 1 degraded grid undervoltage relay setpoints to correct a design deficiency.[18]
September 16, 1986	In another in a series of licensee event reports (LERs) submitted to the NRC by Detroit Edison about its failures to meet the surveillance testing requirements contained in the Fermi 2 technical specifications, the company stated *The cause of these events was an inadequate review of surveillance procedures which resulted from personnel error. Review of procedures is an activity which is controlled by an approved procedure. As a corrective action, the Technical Review process was improved. Among the improvements was the addition of a Technical Review Checklist. The Technical Review Checklist was approved on September 16, 1986.*[19] **UCS View: Detroit Edison proffered the Technical Review Checklist as a "fix" for past sins. Yet this purported "fix" failed dozens of times when revisions to the degraded voltage protection system test**

APPENDIX 1: TIMELINE

Date	Event
	procedure were approved despite having the wrong acceptance criterion.
May 14, 1987	The NRC fined Detroit Edison $100,000 for seven violations involving failure to satisfy surveillance testing requirements in the technical specifications. The NRC stated: *The base value of a civil penalty for a Severity Level III violation or problem is $50,000. … The base civil penalty amount has been increased by 100 percent because: (1) your prior performance in the surveillance testing area since issuance of your operating license in April 1985 has been poor in that Severity Level IV violations have been issued and an Enforcement Conference was held in May 1986 concerning this area and (2) your corrective actions to prevent recurrence of the violations described in the February 1987 Enforcement Conference were incomplete in that you had not initiated an appropriate and comprehensive program to reexamine the technical adequacy of the surveillance and preoperational test procedures.*[20]
May 23, 1987	Reinforcing the $100,000 fine issued by the NRC just nine days earlier for seven violations of surveillance test requirements, Detroit Edison notified the NRC that it had not been performing the surveillance test of the carbon dioxide fire protection function for the standby gas treatment system. The company promised, yet again, to undertake actions to identify and correct the surveillance program deficiencies.[21]
June 26, 1987	Reminiscent of the inadvertent, unrecognized reactor criticality event that occurred on July 3, 1985, there was an unmonitored, uncontrolled reactor mode change event at Fermi Unit 2.[22]
July 27, 1987 to August 7, 1987	In response to the unmonitored, uncontrolled reactor mode change event that occurred one month ago, an NRC inspection team spent 12 days at Fermi Unit 2 and reported: *Six significant events occurred during the inspection period which provided an opportunity for team members to observe operator actions. In general, the team found examples of operator inattentiveness, instances of unfamiliarity with equipment and system operating characteristics, and the absence of a questioning, problem-oriented attitude that asked "what if" questions in an effort to identify and prevent problems.*[23]
July 31, 1987	Detroit Edison voluntarily shut down Fermi Unit 2 for a maintenance outage.[24]
August 3, 1987	An NRC inspector following up on the surveillance testing violations reported: *In response to LER 87-019 mentioned above, the licensee committed to*

APPENDIX 1: TIMELINE

Date	Event
	verify: 1) that procedures were available and responsive to each TS surveillance requirement line item by July 31, 1987; 2) that the TS procedure index would be verified accurate by August 31, 1987; and 3) that an independent sample verification of these activities would be conducted during September 1987. … As of August 3, 1987, the TS Procedure verification required to be completed by July 31, 1987 was less than 50 percent complete. Of 417 review packages, 20 had been completed, about 50 were awaiting supervisor review, and about 200 had been rejected by supervisory review and were under correction or resubmittal for review. … The inspector was unable to obtain a firm completion date.[25]
September 8, 1987	Another NRC inspector began a follow-up examination of Detroit Edison's efforts to correct deficiencies in its surveillance testing program.[26]
October 9, 1987	The NRC Regional Administrator authorized Detroit Edison to restart Fermi Unit 2 following a maintenance outage, but limited the reactor's output to 50 percent of its licensed power level.[27]
October 23, 1987	The NRC inspector completed the examination of the surveillance testing program initiated on September 8, 1987, and reported: ❑ Prior to October 23, 1987, Detroit Edison had not been testing all portions of the RCIC and HPCI systems because the testing had not provided the level of overlap such that the entire system was tested. ❑ Prior to October 23, 1987, Detroit Edison had not been response time tested all portions of the HPCI system because the testing had not provided the level of overlap such that the entire system response time was measured. ❑ Prior to October 23, 1987, Detroit Edison's surveillance testing of the RCIC remote shutdown initiation switch and RCIC valves E51-F045 and F059 switch failed to verify the components to be OPERABLE.[28]
October 23, 1987	The NRC informed Detroit Edison about the results from its Operational Safety Team Inspection at Fermi Unit 2. The NRC stated: *The NRC team effort focused on: the effectiveness of management oversight of plant operations and in communicating the goals and objectives of programs designed to correct operational problems to plant operating staff; the control and effectiveness of plant operating procedures and practices; a review of surveillance test programs and related procedures in conformance with Plant Technical Specification requirements; the effectiveness of administrative procedures and controls; organizational interfaces and coordination in support of plant operation; the adequacy of safety reviews and the process for proposing and implementing plant modifications and corrective actions; training program effectiveness; and a review of programs for assuring quality in*

APPENDIX 1: TIMELINE

Date	Event
	these areas.[29]

The inspection findings affirmed prior staff assessments that the problems at your station encompass a broad range of plant activities, including operating practices, administrative controls, surveillances, training, and the corrective action process. … In the Regional Administrator's letter to you dated October 9, 1987 authorizing plant restart, … you were also directed to submit detailed plans for improvement in the plant's Technical Specifications and their interpretation and implementation, and to prepare a comprehensive report of your various improvement programs and commitments to the NRC.[30]

The team's findings disclosed no new, significant programmatic or managerial deficiencies which, if remedied, would dramatically improve the licensee's ability to safely operate the facility.[31]

Operators did not appear to understand the use of the Technical Specifications (TS) as a "working" document by being intimately familiar with requirements for operability of systems and time limitations.[32]

Operators had a production orientation that regularly resulted in the licensee taking the path of least resistance in resolving administrative and material problems which had the potential to delay progress toward commercial operation.[33]

Based on an examination given to operators by the licensee as a result of the mode change incident and on interviews and observations, the team concluded that operators were not fully knowledgeable in the duties and responsibilities of their individual positions. Operators, instrument technicians, and maintenance personnel did not seem to grasp the significance of how their actions had the potential to place the plant at risk.[34]

The licensee continued to encounter difficulty with the surveillance program. The licensee's plans to minimize missed surveillances remained unfulfilled after several attempts.[35]

The team considered the site QA program as a strength, although QA at times failed to grasp the fundamental causes of problems.[36]

The inspector noted that recent attrition from the [QA] group had caused a rolling backlog of about 15-18 overdue surveillances out of the 24 scheduled as of August 9, 1987.[37]

UCS View: The NRC assumed the role of "pot" to Detroit Edison's "kettle." NRC asserted that Detroit Edison had a "production orientation," yet the NRC Regional Administrator duplicated this

APPENDIX 1: TIMELINE

Date	Event
	characteristic on October 9, 1987, when he allowed Fermi Unit 2 to be restarted but operated at no more than 50 percent power until all identified problems were corrected. A proper "safety orientation" would have resulted in BOTH Detroit Edison and the NRC giving these longstanding problems more than mere lip service.
December 9, 1987	The NRC informed Detroit Edison about the results from its inspection into the efforts by the company to resolve recurring surveillance testing program problems: *At the time of this inspection, the licensee was in the process of improving their surveillance program. This included rewriting and changing the format of over 500 procedures. Technical Specifications were being reviewed (as the result of DER-87-286 and corrective actions as stated in LER 87-019) to ensure the following: each requirement was covered by an approved procedure; … and the procedures contained steps which implemented the required Technical Specification.*[38] **UCS View: It is highly implausible that a serious effort to verify "each requirement was covered by an approved procedure … and the procedures contained steps which implemented the required Technical Specification" would fail to discern that the Division 1 degraded voltage protection setpoint in the technical specification did not match the setpoint in the test procedure. What is far more likely is that the scope and depth of this "band-aid" was overblown by Detroit Edison and not checked by NRC.**
February 26, 1988	Detroit Edison began shutting down Fermi Unit 2 after the engineering department determined that all four emergency diesel generators had not been adequately tested. Specifically, the degraded voltage mod for both the Division 1 and Division 2 emergency diesel generators had never been tested, even though required in the Technical Specifications. All four emergency diesel generators were declared inoperable due to the lack of degraded voltage mode testing, requiring the reactor to be shut down within 12 hours. Shortly after midnight (early on February 27th), operators manually scrammed the reactor from 10 percent power.[39] **UCS View: This event marks the greatest single opportunity for Detroit Edison and the NRC to have noticed that the Division 1 degraded voltage protection setpoint in the technical specifications did not match that in the associated test procedure. After all, Detroit Edison had to shut down Fermi Unit 2 after finding that degraded voltage testing had not been performed as required by technical specifications. There's no explanation for how both Detroit Edision and the NRC allowed Fermi Unit 2 to restart without having found and fixed the discrepancy.**
1989	Detroit Edison committed to the NRC that it would complete a self-initiated Design Bases Document (DBD) Program. The scope of the DBD program covered

APPENDIX 1: TIMELINE

Date	Event
	the Fermi 2 safety related systems, including the emergency diesel generators. Detroit Edison told the NRC that the validation process for each DBD would identify and correct additional discrepancies between information in the DBDs, as-built documents, procedures, Updated Final Safety Analysis Report, and the Operating License.[40] **UCS View: Detroit Edison developed and issued a Design Basis Document for the emergency diesel generators, yet somehow failed to identify the discrepancy between the degraded voltage setpoint in the technical specifications and the associated test procedure. One of the primary purposes of the DBD effort was not met.**
April 27, 1989	The NRC conducted an enforcement conference with Detroit Edison on violations stemming from numerous NRC inspections conducted between 1984 and 1986 at Fermi Unit 2. The violations ranged from certifying that the technical specifications were accurate to having deliberately provided false information to the NRC about access controls for security information.[41]
February 12, 1990	The NRC sanctioned Detroit Edison for numerous violations identified between 1984 and 1986 and discussed at the enforcement conference about a year earlier. The NRC did not fine the company, but scolded it severely: *It was only fortuitous that no safety problems resulted from the operation of Fermi with inaccurate technical specifications.* [42] *We realize that most of the individuals involved in the violations described in the Notice are no longer employed in the Fermi nuclear program.*[43] *The inadequate certification of your Technical Specifications, and the management systems that allowed them to occur are intolerable in the nuclear power industry.*[44] The NRC noted that the manager who had deliberately lied to the NRC about security information access controls still worked for Detroit Edison, but in a part of the organization outside nuclear power. The NRC ordered Detroit Edison to let the agency know before it returned that individual to its nuclear program. **UCS View: The NRC would tolerate the "intolerable" for 16 more years. NRC's strong words were backed by weak (in)action.**
March 4, 1991	The NRC notified Detroit Edison and other nuclear plant owners about testing problems for emergency diesel generators. The NRC expressly informed Detroit Edison: *… some EDG testing has not adequately verified the capability of the EDG to carry its maximum expected loads and other tests have failed to properly verify the operation of the load shedding logic for the EDG.*

APPENDIX 1: TIMELINE

Date	Event
	These testing deficiencies indicate that other licensees may have similar deficiencies that have not yet been detected. It is expected that recipients will review the information for applicability to their facilities and consider actions, as appropriate, to avoid similar problems.[45]
April 28, 1991	Less than eight weeks after being warned about inadequate testing of the emergency diesel generators, Detroit Edison inadequately tested all four of its emergency diesel generators. A technician calibrated the four degraded grid undervoltage and four loss of voltage relays, but left the loss of voltage relays outside the tolerance band specified in the calibration procedure. Worse, the degraded grid undervoltage relays were left outside of the allowable values in the Technical Specifications. During the review of the completed calibration procedure, the shift technical advisor and the nuclear shift supervisor signed the calibration package without noticing the failed results. The system engineer later caught the failure and had all the relays properly recalibrated.[46]
July 29, 1991 to August 30, 1991	The NRC conducted an electrical distribution system functional inspection at Fermi Unit 2. According to the NRC: *The team reviewed the electrical and mechanical support systems of the EDS, examined installed EDS equipment, reviewed EDS testing and procedures, and interviewed selected corporate and site personnel.* [47] *The team verified conformance with General Design Criteria (GDC) 17 and 18 and the applicable 10 CFR 50, Appendix B criteria. The team also reviewed plant technical specifications (TS), the updated safety analysis report (USAR), and appropriate safety evaluation reports (SERs) to verify that TS requirements and licensee commitments were met.* [48] Years later, Detroit Edison provided this recollection of the NRC effort: *An Electrical Distribution System Functional Inspection (EDSFI) was conducted by the NRC in August 1991. The inspection team assessed the performance capability of the Fermi 2 Electrical Distribution System (EDS), including all emergency sources of power to systems required to remain functional during and following design basis events.* [49] **UCS View: The NRC conducted a lengthy, focused inspection of the electrical distribution system but somehow failed to identify that the test procedure for the degraded voltage protection system used the wrong acceptance criterion. That this focused NRC effort failed to detect the glaring discrepancy between technical specifications and testing procedures suggests only one thing to UCS – that NRC inspectors are checking to see if licensees are doing what they say they'll do (i.e., following their procedures) rather than doing what they're required to do (i.e., comply with technical specifications). It's Millstone all over again, only this time the NRC inspectors are**

APPENDIX 1: TIMELINE

Date	Event
	neglecting technical specifications rather than Updated Final Safety Analysis Reports.
July 15, 1994	Detroit Edison discovered yet another failure to conduct adequate surveillance testing per Technical Specification requirements: *During a routine review of surveillance procedure 42.302.02, "Calibration and Logic System Functional Test of Division 1 4160 Volt Emergency Bus 64B and 11EA Undervoltage Circuits," it was determined that the permissive interlocks for the bus undervoltage relays have not been tested to the degree necessary to fully meet the requirements of Technical Specification section 3.3.3. Further testing deficiencies were identified on September 9, 1994 related to the starting and loading of the Emergency Diesel Generators. All Emergency Diesel Generators were declared inoperable.*[50] In response to this oversight, Detroit Edison told the NRC it had taken these corrective steps: *In 1994, during a periodic review of electrical surveillance testing procedures for logic system functional surveillance testing of safety related equipment, Detroit Edison identified problems associated with inadequate overlap of surveillance test procedures. For example, permissive interlocks for the bus undervoltage relays for the Division 1 4160 Volt Emergency Bus 64B and 11EA Undervoltage Circuits had not been tested to the degree necessary to fully meet the requirements of the Technical Specifications. … Corrective actions including revising the deficient procedures and performing the surveillances, and reviewing similar surveillances.*[51]
October 7, 1994	Detroit Edison informed the NRC that the company's initial evaluation of the surveillance testing deficiencies identified in July indicated the problem was not isolated, prompting the company to expand its efforts: *A comprehensive review of the LOP and the LOP/LOCA procedures, schematics, load diagrams, design calculations and overlaps is being performed to ensure that all of the loads and logics are being properly tested. Likewise, a review of all other Technical Specification section 4.8 surveillance requirements is being performed to ensure that the surveillance procedures are adequate to perform the required testing.*[52] **UCS View: This event, following many prior events of similar nature, reveals the futility of having Detroit Edison conduct reviews of surveillance tests without first having determined why previous reviews failed. This review failed to identify the incorrect degraded voltage protection system setpoint as had all prior reviews. While six half-hearted attempts are better than five, what is best is one whole-**

APPENDIX 1: TIMELINE

Date	Event
	hearted attempt. The NRC must make Detroit Edison first figure out the errors of its ways and correct them for there to be any hope that the next attempt will be successful.
January 20, 1995	NRC warned Detroit Edison and all other plant owners about testing methods causing undervoltage protection relay settings being out of tolerance.[53]
November 1995	Detroit Edison began an effort to convert the Fermi Unit 2 Technical Specifications to the Improved Technical Specification format. Detroit Edison described the conversion process to the NRC: *Detroit Edison has undertaken an initiative to convert the Fermi 2 Technical Specifications to the Improved Technical Specifications (ITS). Major benefits sought by this conversion include improved operational safety, clearer understanding of Technical Specification requirements, and reduced administrative burden. … The development phase of the Fermi 2 ITS began in November of 1995 and continues until submittal of the proposed Fermi 2 ITS (expected in second quarter of 1997). … In addition to the benefits expected after implementation, the effort involved in developing the ITS Bases is providing additional confidence in the adequacy and accessibility of design bases information. Development of the Bases requires incorporation of Fermi 2 design information into the generic ITS Bases. This is providing an opportunity to clearly document the origin and intent of the requirements in the Technical Specifications. The level of review of these ITS drafts, including the Onsite Review Organization, provide further assurance that the design and licensing bases are accurately understood and adequately addressed in the ITS Bases*.[54]
February 5, 1996	During a test run, a pump providing cooling water to an emergency diesel generator malfunctioned when freezing weather conditions caused ice to form and build up in the piping. Despite the obvious potential for common-mode failure affecting the pumps for the other emergency diesel generators, workers "*did not immediately recognize the possibility that other cooling water systems for plant safety equipment might be affected by the weather*."[55]
February 6, 1996	During a test run of another emergency diesel generator, a pump providing it with cooling water operated erratically due to the buildup of ice.[56]
May 22, 1996	The NRC proposed a $50,000 fine on Detroit Edison for a violation stemming from the emergency diesel generator cooling pump problems encountered on February 5th and 6th. [57] **UCS View: "Regulatory Whimsy" is the only way to explain how the NRC could fine Detroit Edison $50,000 for a problem that impaired the emergency diesel generators for perhaps 20 hours yet impose no sanction for a problem that impaired the emergency diesel generators**

APPENDIX 1: TIMELINE

Date	Event
	for over 20 years.
1996	In response to the configuration management problems identified at Millstone and reported by NRC to all other nuclear plant owners, Detroit Edison conducted a systematic review of the Fermi Unit 2 Updated Final Safety Analysis Report using subject matter experts such as system and design engineers. Detroit Edison informed the NRC: *While the UFSAR Overview was not a complete verification or validation, the subject matter experts were expected to identify any significant discrepancies between the UFSAR and plant configuration and operation.*[58]
1996	The NRC conducted an Operational Safety Inspection at Fermi Unit 2 to evaluate the effectiveness of the process for identifying, resolving, and preventing issues that degrade the quality of plant operations or safety. "*The inspection identified instances where corrective actions were not effective in preventing problem recurrence*." [59]
February 7, 1997	On October 9, 1996, the NRC required Detroit Edison to formally respond to questions about the available and adequacy of design bases information for Fermi Unit 2. This NRC action resulted from its discovery earlier in 1996 that the three reactors at the Millstone nuclear plant in Connecticut had operated for many years outside of its design and licensing bases. Detroit Edison responded, under oath, to the NRC with these statements: *Based on the information derived from these programs and activities, Detroit Edison concludes that there is reasonable assurance that Fermi 2 is configured, operated and maintained within the design bases.*[60] The assorted "programs and activities" cited by and relied upon by Detroit Edison included: *Detroit Edison has improved the accessibility of licensing bases information by creating electronically searchable files containing text and tabular information from a number of relevant documents, such as the UFSAR, plant Technical Specifications, and NRC Safety Evaluation Reports. Access to these files is available site-wide.*[61] *Surveillance Procedures provide the necessary steps to perform the required periodic testing of safety related structures, systems, and components in accordance with the Technical Specification requirements and/or the ASME Boiler and Pressure Vessel (B&PV) code Section XI. ASME and Technical Specification acceptance criteria are derived in part from design bases requirements contained in the UFSAR. Nuclear Shift Supervisor approval is required before performance of surveillance tests. After completion of surveillance tests, the Nuclear Shift Supervisor*

APPENDIX 1: TIMELINE

Date	Event
	reviews tests to verify that they have been successfully performed and meet the acceptance criteria cited in the surveillance procedure.[62] *10 CFR §50 Appendix B and the Fermi 2 Quality Assurance Program require measures be established to ensure that conditions adverse to quality, such as failures, malfunctions, deficiencies, deviations, defective material and equipment, and nonconformances, are promptly identified and corrected.*[63] *Procedures covering operation, maintenance, surveillance, and test activities have been in place since the issuance of the Fermi 2 Operating License. Ongoing internal, third party, and NRC assessment of these controls and their effectiveness provides opportunities to identify and correct nonconformances and their causes.*[64] *Fermi 2 conducted design reviews, plant procedure reviews, and licensing document reviews as part of the Design Basis Document (DBD) program. A DBD validation was performed, as part of the program, with an emphasis on consistency among DBDs, UFSAR, and Technical Specifications.*[65] *"The NRC Electrical Distribution System Functional Inspection (EDSFI) team reviewed most of the electrical design calculations at Fermi 2 and considered them a strength, as documented in the associated NRC Inspection Report.*[66] *The [NRC] team did not identify any operability concerns, and there were no violations of NRC requirements identified. The inspection concluded that emergency power sources were sized properly and adequate voltage was available to essential buses to accommodate EDS loads.*[67] *The objective of this functional evaluation was to assess the adequacy of the Technical Specification Surveillance Program. The elements of the assessment included verification that Tech Spec surveillance requirements were included in procedures.* [68] *Corrective actions included revising the deficient procedures and performing the surveillances, and reviewing similar surveillances. A dedicated team of approximately 40 people was established to conduct this review and correct identified deficiencies. When similar deficiencies were discovered in other logic functional test surveillances, the investigation was expanded. … This initial effort took place over approximately four months and involved review or revision of approximately 100 surveillance procedures.*[69] **UCS View: <u>None</u> of these many programs and activities prevented Detroit Edison from operating Fermi Unit 2 without testing the**

APPENDIX 1: TIMELINE

Date	Event
	Division 1 degraded grid undervoltage relays as required by the Technical Specifications since August 1986. Since Detroit Edison expressly credited these many programs and activities, NRC should insist that the company explain how each one of these programs and activities failed.
June 2, 1998	The NRC approved an amendment to the Fermi Unit 2 operating license that extended the allowable out of service time for an emergency diesel generator from three days to seven days.[70]
September 15, 1998	Workers replaced the underfrequency relays on the emergency diesel generator. When NRC inspectors later reviewed the modification package, they noted mistakes in the review process required by federal regulation 10 CFR 50.59: *Technical Service Request (TSR)-30092, dated September 15, 1998, replaced Emergency Diesel Generator (EDG) underfrequency relay model GE P/N 12SFF21A1A with model 12SFF16A1A. The [NRC] team noted that the blocks in part 4 and part 5 of the 10 CFR 50.59 Preliminary Evaluation were incorrectly marked. The licensee determined this parts equivalency change to be an exempt change not requiring a full 10 CFR 50.59 evaluation, even though the relay model number was changed in UFSAR fig 8.3-4.*[71]
October 8, 1999	Linear reactor 2 on Emergency Diesel Generator 12 failed due to aging. Each emergency diesel generator features three linear reactors in its excitation circuit. The linear reactors provide base excitation voltage when the emergency diesel generator operates unloaded (disconnected from its electrical bus).[72]
March 3, 1999	During a plant-wide process of "green-banding" sight glasses to clearly identify acceptable bands of fluid levels for equipment, workers improperly translated the sight glass "green band" level indicators for the outboard bearing lubricating oil for Emergency Diesel Generator 14. As a result, the top of the clearly marked "green band" remained below the minimum oil level recommended by the vendor for the bearing.[73]
April 1, 1999	The NRC reported "…*an operator did not follow an emergency diesel generator test procedure sequence which caused the emergency diesel generator output breaker to trip open due to a reverse power condition*."[74]
May 1999 to July 1999	Workers replaced the safety-related electrical motor control center buckets for the emergency diesel generators with new buckets. Some of the replacement buckets had control power transformers that were insufficiently sized to ensure adequate voltage to the starter circuits for components under degraded voltage grid conditions. The safety problems introduced by these replacements would remain uncorrected until August 2006.[75]

APPENDIX 1: TIMELINE

Date	Event
October 20, 1999	The NRC reported: *Inattention to detail, lack of self-checking and lack of an effective peer review resulted in an inadvertent trip of emergency diesel generator 14 during testing. An operator used the wrong switch to adjust voltage. The error resulted in the emergency diesel generator voltage regulator circuitry being damaged.*[76]
October 21, 1999	Linear reactor 2 on Emergency Diesel Generator 14 failed due to aging. Each emergency diesel generator features three linear reactors in its excitation circuit. The linear reactors provide base excitation voltage when the emergency diesel generator operates unloaded (disconnected from its electrical bus).[77]
March 23, 2000	The NRC reported its inspectors "observed all or portions of" the post maintenance test conducted following replacement of a bearing on Emergency Diesel Generator 11.[78]
April 12, 2000	Linear reactor 1 on Emergency Diesel Generator 12 failed due to aging. Each emergency diesel generator features three linear reactors in its excitation circuit. The linear reactors provide base excitation voltage when the emergency diesel generator operates unloaded (disconnected from its electrical bus).[79]
May 9, 2000	Linear reactor 1 on Emergency Diesel Generator 11 failed due to aging. Each emergency diesel generator features three linear reactors in its excitation circuit. The linear reactors provide base excitation voltage when the emergency diesel generator operates unloaded (disconnected from its electrical bus).[80]
June 16, 2000	Workers added the wrong lubricating oil to the alternator bearings on Emergency Diesel Generator 11, causing the EDG to be inoperable longer than the 7-days allowed by Technical Specification 3.8.1.1.[81]
September 7, 2000	NRC inspectors reviewed the results of the surveillance test performed for Emergency Diesel Generator 12 with no findings.[82]
October 16, 2000	Detroit Edison Company transmitted Revision 41 to the Fermi Unit 2 Technical Requirements Manual to the NRC. Revision 41 included a revision to the loss of power instrumentation Table TR3.3.8.1-1, but the Division I 4.16 kV emergency bus undervoltage (degraded voltage) trip setpoint remained at 3952 volts.[83] **UCS View: Detroit Edison repeatedly informed NRC, in writing, that the safety requirement for the degraded voltage setpoint was 3952 volts. Despite those repeated reminders, NRC inspectors failed to notice for more than two decades that Detroit Edison was not testing the degraded voltage setpoint to the proper value.**
November 4, 2000	Following a high temperature alarm on the generator bearing for Emergency Diesel Generator 11, NRC inspectors reviewed the requirements of Technical

APPENDIX 1: TIMELINE

Date	Event
	Specification 3.8.1.[84]
January 11, 2001	The NRC reported its inspectors had reviewed Modification 30458 that revised the Bus 64C undervoltage load shed scheme with no findings.[85] **UCS View: As indicated in Figure 1, Bus 64C is part of the Division 1 electrical distribution system which had the wrong undervoltage trip setpoint in its test procedure. So, there was a "finding" that NRC inspectors failed to make during review.**
March 21, 2001	A few hours into the 23-hour endurance run of Emergency Diesel Generator 14, insufficient oil level in the reservoir caused the outboard bearing to overheat and catastrophically fail.[86]
April 18, 2002	The NRC reported its inspectors had reviewed Revision 47 to surveillance test procedure 24.307.15, "Emergency Diesel Generator 12 – Start and Load Test," with no findings.[87]
February 6, 2003	During a test run of Emergency Diesel Generator 11, workers noticed that the exhaust temperature from cylinder 2 was about 100°F below the normal value. The unexpectedly low temperature was attributed to the fuel injector nozzle allowing more fuel oil to flow into the cylinder. The nozzle was sent back to the vendor who found that the torque on the spring that controlled fuel flow rate was set at 20 ft-lbs instead of the required 55 ft-lbs. Workers at Fermi Unit 2 determined that procedure 34.307.001 did not contain sufficient information to ensure the proper torque setting on the injector nozzle spring.[88]
May 23, 2003	Workers initiated a corrective action report (CARD 03-11847) for an unanswered question from the NRC's safety system and design performance capability (SSDPC) inspection team regarding the adequacy of the time delay for the degraded grid undervoltage relay and the assumption made by Detroit Edison that the design basis did not require degraded grid protection to function concurrent with a loss of coolant accident." [89] **UCS View: NRC inspectors questioned the degraded grid undervoltage design bases and Detroit Edison answered it – with no one noticing that the associated test procedure used the wrong value. Hardly a shining moment in regulatory history.**
June 2, 2003	During maintenance, workers failed to properly reconnect a lubricating oil line for Emergency Diesel Generator 12 to the low lube oil pressure switch. Consequently, EDG 12 was unknowingly inoperable from June 2, 2003, until November 8, 2003.[90]
July 30, 2003	The NRC informed Detroit Edison of the results from its Safety System and Design Performance Inspection at Fermi Unit 2:

APPENDIX 1: TIMELINE

Date	Event
	The inspectors reviewed the reliability and availability of electrical systems used for operation of the EECW and EESW Systems. The 4160V voltage system to assess vulnerabilities due to loss of the preferred offsite source and the standby onsite sources (diesel generators) was also reviewed. In particular, the team evaluated the adequacy of undervoltage protection and vulnerability to spurious separation from the offsite source. ... In addition, the undervoltage protection scheme for the safety related 4160V and 480V buses and control circuits were reviewed for proper operation as described in the licensing and design bases, and for proper isolation and separation to assure the independence of redundant circuits.[91] *NRC opened URI 05000341/2003007-02, Non-Conservative Acceptance Limit for the Time Delay Relay Did Not Assure the Availability of the Vital Buses.*[92]
August 13, 2003	A widespread electrical grid outage affected nine operating and one shut down nuclear power reactors in the US, including Fermi Unit 2. The NRC analyzed the risk implications of the grid outage on these nine reactors. Of the eight nuclear power reactors operating at the time, Fermi Unit 2 went the longest time without power – 6 hours and 19 minutes. The second longest power outage was experienced at the FitzPatrick nuclear plant in New York at 2 hours and 49 minutes – 3 ½ hours less outage time than Fermi Unit 2. The NRC reported that the recovery at Fermi Unit 2 was complicated by problems with the backup to the emergency diesel generators: *The combustion gas turbine generator (CTG) failed to start from the control room due to the failure of a battery-powered inverter. The CTG was manually started 3 hours into the event using a portable generator as an alternate source of starting power.*[93]
April 26, 2004	The NRC informed Detroit Edison of the results from routine inspections at Fermi Unit 2: *The inspectors reviewed applicable system health reports, associated CARDs, licensee maintenance rule conduct manual, various surveillance tests, applicable design basis documents, maintenance rule scoping determinations, expert panel meeting notes, monthly monitoring reports, and the control room unit logs for the following systems:* ❑ *Emergency Diesel Generator 11 (R3000)* [94]
July 27, 2004	The NRC closed URI 05000341/2003007-02 regarding potential inadequate undervoltage protection for the emergency diesel generators based on judgment that the corrective actions promised by Detroit Edison would resolve the issue. The corrective actions had not been implemented at the time the NRC issue was closed.[95]

APPENDIX 1: TIMELINE

Date	Event
	UCS View: A year after **raising safety concerns about the undervoltage protection system, the NRC closed those concerns based on its perception of the adequacy of Detroit Edison's intentions to resolve the problem at some unspecified future date. Such regulatory antics give "nonchalance" a bad image.**
August 2, 2004	Workers replaced the output breaker on Emergency Diesel Generator 12 with a refurbished breaker as part of routine preventative maintenance. The post-maintenance test was performed successfully.[96]
August 6, 2004	During an operability test of Emergency Diesel Generator 12, operators could not open the output breaker using either the local or remote control switches. After actuating a test switch to simulate undervoltage, electricians were able to open the output breaker. The output breaker was replaced with the original breaker removed four days earlier.[97] During another operability test of EDG 12, operators heard an abnormal noise and shut down the EDG. Workers found damage to the scavenging blower that necessitated that it be shipped back to the factory. Faced with a pending deadline for restoring EDG 12 to service or shut down Fermi Unit 2, Detroit Edison asked NRC for seven more days.[98]
August 17, 2004	The NRC denied Detroit Edison's request for enforcement discretion that would have allowed Fermi Unit 2 to operate for seven more days beyond the existing seven day Limiting Condition for Operation for EDG 12 out of service. Among the myriad of reasons cited by NRC in its denial: (a) Detroit Edison did not know what caused the scavenging blower on EDG 12 to fail, (b) Detroit Edison did not know how long it might take to repair EDG 12, and (c) Detroit Edison did not know how the scavenging blower problem might impair the other three emergency diesel generators (i.e., perhaps they suffered from the same defect).[99]
March 31, 2005	Detroit Edison submitted its last monthly operating report to the NRC, having sought and obtained NRC's permission to discontinue the reports. Detroit Edison reported that Fermi Unit 2 had been online for a total of 113,619 hours. [100]
October 25, 2005	The NRC informed Detroit Edison of the results from its routine inspection at Fermi Unit 2. The NRC reported: *The inspectors reviewed the licensee's evaluation and management of plant risk for the maintenance and operational activities affecting safety-related equipment listed below. … The inspectors also reviewed Technical Specifications (TSs) requirements and walked down portions of redundant safety systems, when applicable, to verify risk analysis assumptions were valid and applicable requirements were met.* ❑ *Emergency diesel generator (EDG) 13 safety system outage* [101]

APPENDIX 1: TIMELINE

Date	Event
November 2005	The NRC conducted a Safety System and Design Performance Capability (SSDPC) team inspection at Fermi Unit 2. The team focused on two safety systems – the reactor core isolation cooling and emergency diesel generator systems – and their support systems. According to the NRC:

> *The objective of the SSDPC inspection is to assess the adequacy of calculations, analyses, other engineering documents, and operational and testing practices that were used to support the performance of the selected systems during normal, abnormal, and accident conditions.*[102]
>
> *The inspectors reviewed information to verify that actual system condition and tested capability were consistent with the identified design basis.*[103]
>
> *The inspectors reviewed records of selected periodic testing and calibration procedures as well as surveillance procedures to verify that the design requirements of calculations, drawings, and procedures were incorporated in the system and were adequately demonstrated by test results. Test results were also reviewed to ensure that testing was consistent with design basis information.*[104]
>
> *The inspectors reviewed the 4160V voltage system to assess vulnerabilities due to a potential loss of the preferred offsite source and the stand by onsite sources (emergency diesel generators). The inspectors evaluated the adequacy of the licensee's undervoltage protection system.*[105]

During the SSDPC inspection, the NRC questioned whether the control power transformers for the safety-related motor control centers were sized adequately to ensure sufficient voltage for component operability. Detroit Edison did not enter the unanswered question into its corrective action process.[106]

During the SSDPC inspection, the NRC again questioned the adequacy of the undervoltage relay setpoints. Detroit Edison entered the unanswered question into its corrective action process (CARD 05-26685) as it had done during the 2003 SSDPC when the same unanswered question arose.[107] The NRC inspectors reviewed the resolution to the earlier corrective action attempt (CARD 03-11847), found it wanting, and re-opened the issue.[108]

During the SSDPC inspection, the NRC determined that Detroit Edison's calculations failed to verify or check the adequacy of the emergency diesel generator loading against the limits in Technical Specification 3.8.1, which stated that the steady state frequency for the EDGs shall be between 58.59 Hz and 61.2 Hz.[109]

> **UCS View: The NRC assumed the role of "Charlie Brown" to Detroit Edison's "Lucy." In 2003, NRC inspectors raise concerns about undervoltage protection. Detroit Edison enters it into their corrective action process but never fixes it. In 2005, NRC inspectors again raise**

APPENDIX 1: TIMELINE

Date	Event
	concerns about undervoltage protection. Detroit Edison counters by making the same useless promise. And NRC buys it. (Poor ol' NRC, never does kick that football.)
January 13, 2006	The NRC informed Detroit Edison of results from the SSDPC team inspection: *The inspectors identified a Non-Cited Violation of 10 CFR Part 50, Appendix B, Criterion III, "Design Control," for the licensee's failure to translate the design basis requirements for each of the Emergency Diesel Generator starting air systems into specifications, procedures, and instructions. As a result of this failure, no objective evidence existed that the required emergency diesel generator starting air system capacity was being maintained.*[110]
February 2, 2006	Workers replaced the output breaker on Emergency Diesel Generator 12 with a refurbished breaker as part of routine preventative maintenance. Following an earlier replacement attempt in August 2004, workers concluded that the refurbished breaker would work as long as its alignment was verified following installation. Proper alignment was verified. The post-maintenance test was performed successfully.[111]
February 3, 2006	During an operability test of Emergency Diesel Generator 12, operators could not open the output breaker from the local panel. After actuating a test switch to simulate undervoltage, electricians were able to open the output breaker. The output breaker was replaced with the original breaker removed the previous day. Due in part to the breaker failure, Detroit Edison determined that EDG 12 might not be restored to operable status prior to the expiration of the 7-day allowed outage time. A one-time technical specification amendment extending the allowed outage time an additional 7 days was requested by Detroit Edison and granted by the NRC.[112]
April 25, 2006	After a control power fuse for the Emergency Diesel Generator 13 engine room west supply fan blew, workers entered the problem into the corrective action program (CARD 06-22768). The cause of the blown fuse was not determined and was attributed to a random event.[113]
May 4, 2006	On May 4, 2006, the "Licensee determined that it had not been appropriately updating the design calculations associated with the MCC bucket replacements (CARD 06-23147)." [114]
August 15, 2006	"On April 25, 2005, a control power fuse associated with an EDG 13 ventilation fan failed. On August 15, 2006, during a review of the NRC CPT size question and the fuse failure event, the licensee questioned whether the EDG 13 fuse failure could have been a result of increased current or starter delay due to an undersized CPT." [115]

APPENDIX 1: TIMELINE

Date	Event
	"The licensee later questioned whether the CPT size could have contributed to the blown fuse and entered the issue into their corrective action program on August 15, 2006, as CARD 06-25253. The concern was that size 3 motor starters should have had a nominal 250 Volt Amp CPT, whereas several buckets with size 3 starters had 150 Volt Amp transformers. With an under-sized CPT, the secondary voltage drops as the current draw increases due to the load demand of the starting coil. If the secondary voltage dropped below the pick-up voltage of the coil, the coil would draw the full inrush current until the control power fuse blew." [116]
August 25, 2006	"On August 25, 2006, the inspectors noted that surveillance test procedures associated with the Division 1 EDGs included a minimum required voltage of 3740 Volts and questioned the licensee about the appropriateness of the surveillance test acceptance criteria." [117]

UCS View: Twenty-one years after the mistake was made, someone finally notices that the acceptance criterion in the test procedure is non-conservative to the technical specification requirement. It reveals an unrealized dividend of NRC's granting 20-year extensions to nuclear plant operating licenses – it gives NRC inspectors more time to find yesterday's mistakes.

Cited Sources:

[1] Nuclear Regulatory Commission 2005. Standard technical specifications General Electric plants, BWR/4. Report NUREG-1433 Rev. 3, Vol. 1, page 3.3.8.1-3. December.
[2] Gipson, D. R., 1997. The Detroit Edison Company (Fermi 2) response to request for information pursuant to 10 CFR §50.54(f) regarding adequacy and availability of design bases information. Letter to Nuclear Regulatorry Commission, February 7, enclosure page A-13. Douglas R. Gipson was senior vice president, nuclear generation for the Detroit Edison Company.
[3] Dyer, J.E., 2001. Final significance determination for a white finding and notice of violation – Fermi 2 nuclear power plant. Letter to William O'Connor Jr., vice president, nuclear generation, Detroit Edison Company, September 14, enclosure page 1. James E. Dyer was regional administrator for the Nuclear Regulatory Commission.
[4] Thompson, H. L., 1990. Order modifying license and notice of violation (NRC investigation report nos. 3-85-019, 3-86-002, 3-86-006 and 3-86-015). Letter to W. McCarthy, Chairman of the Board and Chief Executive Officer, Detroit Edison Company, February 12, page 3. Hugh L. Thompson Jr., was deputy executive director for nuclear materials, safety, safeguards, and operations support for the Nuclear Regulatory Commission.
[5] Nuclear Regulatory Commission, 1987. Report to Congress on abnormal occurrences. Report NUREG-0900 Vol. 9, No. 2, page 29. January.
[6] Thompson, H.L., 1985. Issuance of facility operating license NPF-43, Fermi-2. Letter to Dr. Wayne Jens, vice president, nuclear operations, Detroit Edison Company, July 15, enclosure page 1. Hugh L. Thompson Jr., was director, division of licensing for the Nuclear Regulatory Commission.
[7] Lenart, R. S., 1986a. Diesel generator start failure. Letter to James G. Keppler, regional administrator, Nuclear Regulatory Commission, January 15, enclosure page 1. Robert S. Lenart was plant manager for the Detroit Edison Company.
[8] Lenart, R. S., 1986b. Transmittal of licensee event report 86-022-02. Letter to Nuclear Regulatory Commission, December 12, enclosure page 2. Robert S. Lenart was plant manager for the Detroit Edison Company.
[9] Pederson, C. D., 2006. Fermi power plant NRC special inspection report 05000341/2006015. Letter to Donald K. Cobb, assistant vice president, nuclear generation, Detroit Edison Company, November 7, enclosure, page 4. Cynthia D. Pederson was director, division of reactor safety for the Nuclear Regulatory Commission.
[10] NRC, 1987, page 29.
[11] Lenart, R. S., 1986c. Emergency diesel generator start failures. Letter to James G. Keppler, Regional Administrator, Nuclear Regulatory Commission, August 7, enclosure page 1. Robert S. Lenart was plant manager for the Detroit Edison Company.
[12] Ibid
[13] Lenart, 1986b, enclosure page 2.
[14] Gipson, 1997, enclosure page A-13.
[15] Lenart, R. S., 1986d. Transmittal of licensee event report 86-022-00. Letter to Nuclear Regulatory Commission, August 6, enclosure page 2. Robert S. Lenart was plant manager for the Detroit Edison Company.
[16] Thompson, 1985, enclosure page 6.
[17] Lenart, R. S., 1986e. Transmittal of licensee event report 86-030-00. Letter to Nuclear Regulatory Commission, September 5, enclosure page 1. Robert S. Lenart was plant manager for the Detroit Edison Company.
[18] Pederson, 2006, enclosure, page 1.
[19] Lenart, 1986b, enclosure page 6.
[20] Davis, A. B., 1987. Notice of violation and proposed imposition of civil penalty (NRC inspection reports no. 50-341/87002(DRP); 50-341/87006(DRP); and 50-341/87008(DRP)). Letter to Walter J. McCarthy, Chief Executive Officer, Detroit Edison Company, May 14, page 2. A. Bert Davis was the regional administrator for the Nuclear Regulatory Commission.
[21] Crutchfield, D. M., 1987. Operational safety team inspection report no. 50-341/87030. Letter to B. Ralph Sylvia, group vice president, nuclear operations, Detroit Edison Company, October 23, enclosure page 9. Dennis M. Crutchfield was director, division of reactor projects for the Nuclear Regulatory Commission.
[22] Crutchfield, 1987, enclosure page 1.
[23] Crutchfield, 1987, enclosure page 3.
[24] Nuclear Regulatory Commission, 1987. Startup authorized after maintenance outage. Preliminary notification of occurrence PNO-III-87-133, October 13.
[25] Crutchfield, 1987, enclosure page 9.
[26] Letter dated December 9, 1987, from Geoffrey C. Wright, Chief – Operations Branch, Nuclear Regulatory Commission, to B. Ralph Sylvia, Group Vice President – Nuclear Operations, Detroit Edison Company, enclosed notice of violation.
[27] Preliminary Notification PNO-III-87-133 dated October 13, 1987, by Nuclear Regulatory Commission, "Startup Authorized after Maintenance Outage."
[28] Wright, G. C., 1987. Letter to B. Ralph Sylvia, group vice president, nuclear operations, Detroit Edison Company, December 9, enclosed notice of violation. Geoffrey C. Wright was chief, operations branch for the Nuclear Regulatory Commission.
[29] Crutchfield, 1987, page 1.
[30] Crutchfield, 1987, page 2.
[31] Crutchfield, 1987, enclosure page 1.
[32] Ibid.
[33] Crutchfield, 1987, enclosure page 2.
[34] Ibid.
[35] Ibid.
[36] Ibid.
[37] Crutchfield, 1987, enclosure page 11.
[38] Wright, 1987, enclosure page 2.
[39] Nuclear Regulatory Commission, 1988. Event Notification No. 11612, February 26.
[40] Gipson, 1997, enclosure page 1-5.
[41] Thompson, 1990, page 1.
[42] Thompson, 1990, page 3.

[43] Ibid.
[44] Ibid.
[45] Nuclear Regulatory Commission, 1991. Inadequate testing of emergency diesel generators (EDGs). Information notice 91-13, March 4, page 1.
[46] Miller, H. J., 1991. Letter to W. S. Orser, senior vice president, nuclear operations, Detroit Edison Company, October 9, enclosure page 11. Hubert J. Miller was director, division of reactor safety for the Nuclear Regulatory Commission.
[47] Miller, 1991, enclosure page i.
[48] Miller, 1991, enclosure page 2.
[49] Gipson, 1997, enclosure page A-4.
[50] Gipson, D. R., 1994. Licensee event report (LER) no. 94-003-01. Letter to Nuclear Regulatory Commission, October 7, enclosure page 1. Douglas R. Gipson was senior vice president, nuclear generation for the Detroit Edison Company.
[51] Gipson, 1997, enclosure page A-39.
[52] Gipson, 1994, enclosure page 9.
[53] Nuclear Regulatory Commission, 1995. Undervoltage protection relay settings out of tolerance due to test equipment harmonics. Information notice 95-05, January 20.
[54] Gipson, 1997, enclosure page A-32.
[55] Nuclear Regulatory Commission, 1996. NRC staff proposes $50,000 fine against Detroit Edison Co. for violation of NRC requirements at Fermi 2 nuclear plant. Press release, May 22.
[56] NRC, 1996.
[57] NRC, 1996.
[58] Gipson, 1997, enclosure pages 1-3 and 1-4.
[59] Gipson, 1997, enclosure page 7-4.
[60] Gipson, 1997, page 1.
[61] Gipson, 1997, enclosure page 1-7.
[62] Gipson, 1997, enclosure page 5-2.
[63] Gipson, 1997, enclosure page 6-3.
[64] Gipson, 1997, enclosure page 7-3.
[65] Gipson, 1997, enclosure page 8-2.
[66] Gipson, 1997, enclosure page A-3.
[67] Gipson, 1997, enclosure page A-5.
[68] Gipson, 1997, enclosure page A-13.
[69] Gipson, 1997, enclosure page A-39.
[70] Kugler, A. J., 1998. Fermi 2 – issuance of amendment re: extension of emergency diesel generator allowed outage times for Fermi 2. Letter to Douglas R. Gipson, senior vice president, nuclear generation, Detroit Edison Company, June 2, page 1. Andrew J. Kugler was project manager for the Nuclear Regulatory Commission.
[71] Grobe, J. A., 2001. Fermi – NRC inspection report 50-341/20000009(DRS). Letter to William O'Connor Jr., vice president, nuclear generation, Detroit Edison Company, September 21, enclosure page 7. John A. Grobe was director, division of reactor safety for the Nuclear Regulatory Commission.
[72] Ring, M. A., 2000a. Fermi inspection report 50-341/20000003(DRP). Letter to William O'Connor Jr., vice president, nuclear generation, Detroit Edison Company, June 16, enclosure page 13. Mark A. Ring was chief, reactor projects branch 1 for the Nuclear Regulatory Commission.
[73] Dyer, 2001, enclosure page 1.
[74] Nuclear Regulatory Commission, 2000. Plant issues matrix, March 31, page 7.
[75] Pederson, 2006, enclosure page 4.
[76] NRC, 2000, page 3.
[77] Ring, 2000a, enclosure page 13.
[78] Ring, M. A., 2000b. Fermi inspection report 50-341/2000001(DRP). Letter to D. R. Gipson, senior vice president, nuclear generation, Detroit Edison Company, March 23, enclosure page 7. Mark A. Ring was chief, reactor projects branch 1 for the Nuclear Regulatory Commission.
[79] Ring, 2000a, enclosure page 13.
[80] Ibid.
[81] Ring, 2000a, enclosure page 16.
[82] Ring, M. A., 2000c. Fermi inspection report 50-341/00-10(DRP). Letter to William O'Connor Jr., vice president, nuclear generation, Detroit Edison Company, October 20, enclosure page 8. Mark A. Ring was chief, branch 1 for the Nuclear Regulatory Commission.
[83] Detroit Edison Company, 2000. Automated record management distribution control list. Letter to Nuclear Regulatory Commission, October 16.
[84] Ring, M. A., 2000d. Fermi inspection report 50-341/00-13(DRP). Letter to D. R. Gipson, Senior Vice President – Nuclear Generation, Detroit Edison Company, December 7, enclosure page 6. Mark A. Ring was chief, reactor projects branch 1 for the Nuclear Regulatory Commission.
[85] Ring, M. A., 2001. Fermi inspection report 50-341/00-14(DRP). Letter to William O'Connor Jr., vice president, nuclear generation, Detroit Edison Company, January 11, enclosure page 7. Mark A. Ring was chief, reactor projects branch 1 for the Nuclear Regulatory Commission.
[86] Dyer, 2001, enclosure page 1.
[87] Ring, M. A., 2002. Fermi 2 nuclear power station NRC inspection report 50-341/02-03(DRP). Letter to William O'Connor Jr., vice president, nuclear generation, Detroit Edison Company, April 18, enclosure page 12. Mark A. Ring was chief, branch 1 for the Nuclear Regulatory Commission.
[88] Ring, M. A., 2003. Enrico Fermi unit 2 NRC integrated inspection report 05000341/2003008. Letter to William O'Connor Jr., vice president, nuclear generation, Detroit Edison Company, October 28, enclosure page 19. Mark A. Ring was chief, branch 1 for the Nuclear Regulatory Commission.
[89] Pederson, 2006, enclosure attachment 3, page 2.
[90] Duncan, E. R., 2004. Fermi power plant, unit 2 NRC integrated inspection report 05000341/2004004. Letter to William O'Connor Jr., vice president, nuclear generation, Detroit Edison Company, July 27, enclosure page 20. Eric R. Duncan was chief , branch 6 for the Nuclear Regulatory Commission.

[91] Lara, J. F., 2003. Fermi 2 nuclear power station NRC safety system design and performance capability inspection report 50-341/03-07(DRS). Letter to William O'Connor Jr., vice president, nuclear generation, Detroit Edison Company, July 30, enclosure page 7. Julio F. Lara was chief, electrical engineering branch within the division of reactor safety for the Nuclear Regulatory Commission.
[92] Pederson, 2006, enclosure attachment 3, page 2.
[93] Ader, C. E., 2006. Transmittal of final ASP analyses (August 14, 2003, grid disturbance events). Memo to Catherine Haney, director, division of operating reactor licensing, Nuclear Regulatory Commission, February 17. Charles E. Ader was director, division of risk analysis and applications for the Nuclear Regulatory Commission.
[94] Ring, M. A., 2004. Fermi power plant, unit 2 NRC integrated inspection report 05000341/2004002. Letter to William O'Connor Jr., vice president, nuclear generation, Detroit Edison Company, April 26, enclosure page 6. Mark A. Ring was chief, branch 1 for the Nuclear Regulatory Commission.
[95] Pederson, 2006, enclosure attachment 3, page 2.
[96] Kozak, T. J., 2006. Fermi power plant, unit 2, NRC integrated inspection report 05000341/2006002. Letter to Donald K. Cobb, assistant vice president, nuclear generation, Detroit Edison Company, May 8, enclosure page 11. Thomas J. Kozak was team leader, technical support services for the Nuclear Regulatory Commission.
[97] Ibid.
[98] Reynolds, S. A., 2004. Denial of a request for notice of enforcement discretion for Detroit Edison Company regarding Fermi 2 (NOED No. 04-3-001). Letter to William O'Connor Jr., vice president, nuclear generation, Detroit Edison Company, August 17. Steven A. Reynolds was acting director, division of reactor projects for the Nuclear Regulatory Commission.
[99] Ibid
[100] Peterson, N. K., 2005. Monthly operating status report for March 2005. Letter to Nuclear Regulatory Commission, April 12, enclosure page 1. Norman K. Peterson was manager, nuclear licensing for the Detroit Edison Company.
[101] Duncan, E., 2005. Fermi power plant, unit 2 NRC integrated inspection report 05000341/2005014. Letter to William T. O'Connor Jr., vice president, nuclear generation, Detroit Edison Company, October 25, enclosure page 5. Eric Duncan was chief, reactor projects branch 6 for the Nuclear Regulatory Commission.
[102] Stone, A. M., 2006. Fermi power plant, unit 2 NRC biennial safety system design and performance capability inspection report 05000341/2005016. Letter to D. Cobb, manager of nuclear generation, Detroit Edison Company, January 13, enclosure page 4. Ann Marie Stone was chief, engineering branch 2 within the division of reactor safety for the Nuclear Regulatory Commission.
[103] Stone, 2006, enclosure page 8.
[104] Stone, 2006, enclosure page 9.
[105] Stone, 2006, enclosure page 14.
[106] Pederson, 2006, enclosure, page 7.
[107] Pederson, 2006, enclosure attachment 3, page 2.
[108] Ibid.
[109] Stone, 2006, enclosure page 10.
[110] Stone, 2006, enclosure page 2.
[111] Kozak, 2006, enclosure page 11.
[112] Ibid.
[113] Pederson, 2006, enclosure, page 7.
[114] Pederson, 2006, enclosure attachment 3, page 3.
[115] Pederson, 2006, enclosure, page 4.
[116] Pederson, 2006, enclosure, pages 7-8.
[117] Pederson, 2006, enclosure, page 5.

UNITED STATES
NUCLEAR REGULATORY COMMISSION
OFFICE OF NUCLEAR REACTOR REGULATION
WASHINGTON, DC 20555-0001

April 12, 2008

NRC INFORMATION NOTICE 2008-05: FIRES INVOLVING EMERGENCY DIESEL GENERATOR EXHAUST MANIFOLDS

ADDRESSEES

All holders of operating licenses for nuclear power reactors, except those who have permanently ceased operations and have certified that fuel has been permanently removed from the reactor vessel.

PURPOSE

The U.S. Nuclear Regulatory Commission (NRC) is issuing this information notice (IN) to inform addressees of fires at nuclear power facilities involving emergency diesel generator (EDG) exhaust manifolds. The NRC expects that addressees will review the information for applicability to their facilities and consider taking actions, as appropriate, to avoid similar problems. However, suggestions contained in this IN are not NRC requirements; therefore, no specific action or written response is required.

DESCRIPTION OF CIRCUMSTANCES

The Office of Nuclear Reactor Regulation recently reviewed operating experience related to EDG fires that have occurred since the beginning of 2003. The following describes several EDG fires that occurred at commercial nuclear power plants.

Calvert Cliffs Nuclear Power Plant, Unit 1

During a surveillance test conducted on August 12, 2007, a small fire ignited on the Calvert Cliffs Nuclear Power Plant, Unit 1, EDG 1B exhaust manifold. The EDG 1B was approximately 1-hour and 20 minutes into a monthly surveillance run and at full load for 17 minutes when the fire occurred. Lube oil leaked from multiple, loose engine top cover bolts onto the exhaust manifold and caused the fire. Operators extinguished the flames with a carbon dioxide fire extinguisher. The small fire lasted approximately 6 minutes. The licensee terminated the surveillance test and unloaded and shut down the EDG. The licensee then examined the engine top cover and discovered that 15 of the 122 bolts were at less than the 40–55 foot-pounds (ft-lbs) torque value specified by the vendor. The licensee tightened these bolts to 55 ft-lbs and verified that all engine top cover bolts on all of the onsite Fairbanks Morse EDGs (1B, 2A, and 2B) were within the vendor-specified torque value. The EDG 1B was returned to an operable status after satisfactory post-maintenance testing. The licensee's procedure for performing the EDG inspection did not specify a torque value for the engine top cover bolts.

ML080440014

The procedure did not reference or incorporate the torque value of 40–55 ft-lbs recommended by the “Fairbanks Morse Engine Technical Manual” (NRC Integrated Inspection Report Nos. 05000317/2007004 and 05000318/2007004, dated November 8, 2007, Agencywide Documents Access and Management System (ADAMS) Accession No. ML073170049).

Arkansas Nuclear One (ANO), Unit 2

On August 27, 2003, the licensee performed a planned monthly surveillance test run of the ANO, Unit 2 EDG 2K-4A (Fairbanks Morse) and EDG 2K-4B. During this run, a small flash fire occurred on the exhaust manifold that self-extinguished after a few seconds. The fire resulted from oil leaking past the exhaust manifold gasket for cylinders 7, 8, and 9 and onto the external surface of the exhaust manifold. The oil on the exhaust manifold flashed into flames when the surface temperature reached approximately 260 °C (500 °F). Licensee corrective actions included replacing all exhaust manifold gaskets. Eleven months earlier, the licensee had prepared a maintenance action item for EDG 2K-4B noting that an oil leak had developed on the exhaust manifold for cylinders 7, 8, and 9. (NRC Integrated Inspection Report Nos. 0500313/2003004 and 0500368/2003004, dated November 4, 2003, ADAMS Accession No. ML033090130)

On April 15, 2007, the licensee performed a surveillance run of the ANO Unit 2 EDG 2K-4A. During this run, operators observed smoke coming from underneath the insulation on both four-barrel collectors, one on each side of the EDG. The operators observed that, occasionally, a small flash flame would appear and self extinguish. The flame and smoke ceased by the time full load was achieved and the 24-hour run was completed with no additional flame or smoke. The insulation on this EDG had been replaced 4 days earlier. The licensee determined that the actual insulation material was not damaged but the insulation cover material had started to burn as the EDG exhaust system heated up. The cover material was rated only to 260 °C (500 °F), and the expected temperature of the exhaust piping was 538 °C (1,000 °F). The licensee had also installed the same type of insulation 13 days earlier on EDG 2K-4B. As part of its corrective action, the licensee replaced the insulation on both EDGs with insulation with an outer wrap appropriately rated for the expected temperatures. (NRC Integrated Inspection Report Nos. 05000313/2007003 and 05000368/2007003, dated August 3, 2007, ADAMS Accession No. ML072180555)

On May 11, 2007, the licensee performed a monthly surveillance run of the ANO Unit 2 EDG 2K-4A. The EDG had been running fully loaded for approximately 10 minutes when the operators observed a small fire that appeared to originate from under the insulation on an exhaust manifold. The operators observed the fire for approximately 20 seconds and concluded that it was not going to burn out. The operators extinguished the fire with a fire extinguisher. Control room operators unloaded and secured the EDG. The licensee removed the insulation from the four-barrel collector adjacent to the exhaust manifold and discovered that approximately 16 square inches were saturated with oil. The licensee determined the source of the oil was front cover of the EDG and the root cause was uncorrected equipment problems. The licensee did not adequately implement corrective actions from a 2003 diesel exhaust manifold fire in that the periodic inspections for oil leakage by operators and system engineers did not identify the oil leakage from the front cover. (NRC Integrated Inspection

Report Nos. 5000313/2007003 and 05000368/2007003, dated August 3, 2007, ADAMS Accession No. ML072180555)

On August 3, 2007, the licensee started and loaded the ANO, Unit 2 EDG 2K-4A for a monthly surveillance test. The EDG had been running fully loaded for approximately 1-minute when the operators observed a fire on the exhaust system. The fire appeared to originate from the inspection cover plate on the bottom side of the four-barrel collector assembly, which connects the exhaust header to the turbocharger. When control room operators unloaded the EDG, the intensity of the fire diminished significantly. After the EDG was secured, two small flames were observed coming from the inspection cover plate. An operator extinguished the flames using a fire extinguisher. The licensee determined the root cause of this event was a warped four-barrel inspection cover plate. This inspection cover plate had been removed from an existing four-barrel collector then installed on a spare four-barrel collector when the spare was installed during maintenance on May 11, 2007. The licensee's maintenance procedure used for the replacement of the four-barrel inspection cover plate did not specify performing flatness checks. As a result, oil leakage from the inspection cover plate caused an exhaust system fire. (NRC Integrated Inspection Report Nos. 05000313/2007004 and 05000368/2007004, dated October 24, 2007, ADAMS Accession No. ML073520276)

North Anna Power Station, Unit 2

In September 2006, a fire occurred on the North Anna Power Station Unit 2 EDG H exhaust manifold. The licensee determined the fire was caused by lube oil leakage past an exhaust manifold connection onto the external surface of the manifold. The licensee attributed the lube oil leakage to the elongation of exhaust manifold bolts. The Unit 2 EDG exhaust manifold bolting had been replaced in the spring of 2006. As corrective actions, specific preventive maintenance inspections were implemented to monitor the condition of newly installed exhaust manifold bolts and replace degraded bolting if required. In addition, a preventive maintenance task was generated to replace exhaust manifold bolting on a six-year frequency. (NRC Integrated Inspection Report Nos. 05000338/2006004 and 05000339/2006004, dated October 30, 2006, ADAMS Accession No. ML063030486)

Fermi Power Plant, Unit 2

On January 31, 2003, the licensee performed a post-maintenance test run of the Fermi Power Plant, Unit 2 EDG 11. During this run, the licensee noticed fuel oil spilling from the clean fuel drain header vent (J-tube) onto the injector deck. The fuel oil migrated from the deck onto the hot exhaust manifold. The high temperature of the exhaust manifold ignited the fuel oil on both sides of EDG 11. Plant personnel extinguished the fire, and the operators shutdown the EDG. Fourteen days earlier, the licensee had installed temporary plastic sleeves on the drain lines of the clean fuel drain header for all four EDGs without following the temporary modification process. The plastic sleeves on the drain line of the clean fuel drain header restricted flow causing the fuel oil to flow out the J-tube vent. The fuel oil then collected on the injector deck, migrated, and collected on the exhaust manifold insulation and ignited. (NRC Integrated Inspection Report No. 05000341/2003008, dated October 28, 2003, ADAMS Accession No. ML033040141)

Peach Bottom Atomic Power Station

On April 19, 2003, a small fire occurred on the Peach Bottom Atomic Power Station EDG E2 exhaust manifold heat shield. Lube oil leakage from an engine top cover bolted flange connection dripped onto the protective heat shield that covers the hot exhaust manifold where it smoldered and occasionally flashed into a small flame, then burned out. After completion of the EDG E2 test, operations personnel removed the EDG E2 from service and performed corrective maintenance to repair the lube oil leak. The cause of the lube oil leakage was that several bolts on the EDG E2 top cover flange were found at approximately one-half of the torque values specified by the EDG manufacturer. This occurred because the licensee's EDG maintenance procedure did not specify tightening the bolts to the EDG manufacturer torque values and instead specified a tightness value of 'wrench-tight'. (NRC Integrated Inspection Report Nos. 05000277/2003003 and 050000278/2003003, dated July 24, 2003, ADAMS Accession No. ML032050207)

BACKGROUND

NRC fire protection regulations for commercial nuclear power plants ensure that, in the event of fire in any area of the plant, at least one train of equipment needed to achieve and maintain safe-shutdown conditions in the reactor will remain free of fire damage. The regulations in Title 10 of the *Code of Federal Regulations* (10 CFR) Part 50, "Domestic Licensing of Production and Utilization Facilities," require each operating nuclear power plant to have a fire protection plan. This plan must satisfy Appendix A to Part 50, "General Design Criteria for Nuclear Power Plants," specifically General Design Criterion (GDC) 3, "Fire Protection," as required by 10 CFR 50.48(a).

Components within the scope of 10 CFR 50.55a are included in the scope of 10 CFR 50.65, "Requirements for Monitoring the Effectiveness of Maintenance at Nuclear Power Plants" (the "Maintenance Rule"). The Maintenance Rule requires that licensees monitor the performance or condition of structure, system, and components (SSCs) against licensee-established goals in a manner sufficient to provide reasonable assurance that such SSCs are capable of fulfilling their intended function. Such goals are to be established, where practicable, commensurate with safety, and they are to take into account industry-wide operating experience. When the performance or condition of a component does not meet established goals, appropriate corrective actions are to be taken.

DISCUSSION

Licensees rely on EDGs to provide emergency alternating current power in response to loss of offsite power events. EDGs are required to be operable as specified in plant technical specifications. Although these EDG exhaust manifold fires since 2003 did not disable the EDGs, the fires caused the licensees to shut down the EDGs, rendering them unavailable until the licensees could correct the causes of the fires.

The several fires were attributed to leaking exhaust manifold connections on Fairbanks-Morse opposed piston EDGs. This type of EDG is susceptible to oil leaking past the piston rings into the cylinder. The top piston is especially susceptible as there is oil on the surfaces above the piston. During standby conditions and at low loads, oil leaking past the piston rings will collect in the cylinders. At low loads, the exhaust temperatures are not sufficient to burn the oil in the cylinder, and the excess oil will be exhausted into the exhaust manifold with the exhaust gases. At full load, the combustion temperature is sufficient to completely burn any oil seeping past the piston rings. Any oil carried over into the engine exhaust can ignite when in contact with a hot exhaust manifold and in the presence of air. In particular, oil that passes through leaking exhaust manifold connections can collect in the insulation on the exterior of the exhaust manifold and can ignite when the exhaust manifold becomes hot.

In addition, several exhaust manifold fires were caused by oil leakage that migrated to the hot exhaust manifold. The oil leakage was attributed to loose fasteners on inspection covers and top covers. In some cases, the licensee's maintenance procedure did not specify or reference the vendor-recommended torque values for the fasteners.

CONTACT

This IN does not require any specific action or written response. Please direct any questions about this matter to the technical contacts listed below or the appropriate project manager in the NRC's Office of Nuclear Reactor Regulation.

/RA by TQuay for/

Michael J. Case, Director
Division of Policy and Rulemaking
Office of Nuclear Reactor Regulation

Technical Contacts: Naeem Iqbal, NRR
301-415-3346
E-mail: nxi@nrc.gov

Robert J. Wolfgang, NRR
301-415-1624
E-mail: rjw1@nrc.gov

Note: NRC generic communications may be found on the NRC public Web site, http://www.nrc.gov, under Electronic Reading Room/Document Collections.

the cylinder. The top piston is especially susceptible as there is oil on the surfaces above the piston. During standby conditions and at low loads, oil leaking past the piston rings will collect in the cylinders. At low loads, the exhaust temperatures are not sufficient to burn the oil in the cylinder, and the excess oil will be exhausted into the exhaust manifold with the exhaust gases. At full load, the combustion temperature is sufficient to completely burn any oil seeping past the piston rings. Any oil carried over into the engine exhaust can ignite when in contact with a hot exhaust manifold and in the presence of air. In particular, oil that passes through leaking exhaust manifold connections can collect in the insulation on the exterior of the exhaust manifold and can ignite when the exhaust manifold becomes hot.

In addition, several exhaust manifold fires were caused by oil leakage that migrated to the hot exhaust manifold. The oil leakage was attributed to loose fasteners on inspection covers and top covers. In some cases, the licensee's maintenance procedure did not specify or reference the vendor-recommended torque values for the fasteners.

CONTACT

This IN does not require any specific action or written response. Please direct any questions about this matter to the technical contacts listed below or the appropriate project manager in the NRC's Office of Nuclear Reactor Regulation.

/RA by TQuay for/

Michael J. Case, Director
Division of Policy and Rulemaking
Office of Nuclear Reactor Regulation

Technical Contacts: Naeem Iqbal, NRR
301-415-3346
E-mail: nxi@nrc.gov

Robert J. Wolfgang, NRR
301-415-1624
E-mail: rjw1@nrc.gov

Note: NRC generic communications may be found on the NRC public Web site, http://www.nrc.gov, under Electronic Reading Room/Document Collections.

Distribution:
IN Reading File James Smith, NMSS

ADAMS Accession Number: ML080440014 NRR-052

OFFICE	AFPB:DRA	CPTB:DCI	TECH EDITOR	BC:CPTB:DCI	BC:AFPB:DRA
NAME	NIqbal	RWolfgang	HChang	JMcHale	AKlein
DATE	03/17/2008	03/19/2008	03/14/2008	03/20/2008	03/27/2008
OFFICE	D:DRA	LA:PGCB:DPR	PGCB:DPR	BC:PGCB:DPR	D:DPR
NAME	MCunningham	CHawes	DBeaulieu	MMurphy	TQuay for MCase
DATE	04/02/2008	04/07/2008	04/04/2008	04/10/2008	04/12/2008

OFFICIAL RECORD COPY

UNITED STATES
NUCLEAR REGULATORY COMMISSION
OFFICE OF NUCLEAR MATERIAL SAFETY AND SAFEGUARDS
OFFICE OF NUCLEAR REACTOR REGULATION
OFFICE OF NEW REACTORS
WASHINGTON, DC 20555-0001

February 26, 2010

NRC INFORMATION NOTICE 2010-04: DIESEL GENERATOR VOLTAGE REGULATION SYSTEM COMPONENT DUE TO LATENT MANUFACTURING DEFECT

ADDRESSEES

All holders of an operating license or construction permit for a nuclear power reactor issued under Title 10 of the *Code of Federal Regulations* (10 CFR) Part 50, "Domestic Licensing of Production and Utilization Facilities," except those who have permanently ceased operations and have certified that fuel has been permanently removed from the reactor vessel.

All holders of or applicants for an early site permit, standard design certification, standard design approval, manufacturing license, or combined license issued under 10 CFR Part 52, "Licenses, Certifications, and Approvals for Nuclear Power Plants."

All holders of or applicants for a license for a fuel cycle facility issued pursuant to 10 CFR Part 70, "Domestic Licensing of Special Nuclear Material."

PURPOSE

The U.S. Nuclear Regulatory Commission (NRC) is issuing this information notice (IN) to alert addressees to possible latent manufacturing defects in emergency diesel generator (EDG) voltage regulation components. The NRC expects that recipients will review the information for applicability to their facilities and consider actions, as appropriate, to avoid similar problems. Suggestions contained in this IN are not NRC requirements; therefore, no specific action or written response is required.

DESCRIPTION OF CIRCUMSTANCES

On November 12, 2008, during the performance of a monthly surveillance test at Palo Verde Nuclear Generating Station Unit 2, the train 'A' EDG tripped on a generator differential protective relay trip shortly after paralleling it to offsite power. The licensee declared the EDG inoperable.

Licensee troubleshooting revealed damage to the excitation control system for the generator on one of the three phase alternating current voltage inputs to the rectifier bridge. The damaged electrical component was found to be the 'C' phase linear power reactor. A linear power reactor is an electrical component consisting of a magnetic coil (inductor). The linear power reactor function is to limit the magnitude of the current through the excitation bridge, which supplies the generator field during operation. The licensee inspection of the failed magnetic coil found burnt

ML093340392

and charred copper conductors and insulation materials. No additional electrical components in the cabinet were found damaged or operating out of specifications. Troubleshooting also revealed that the failure was isolated to this component and not caused by any other component in the voltage regulation system.

The licensee sent the failed linear power reactor to an external laboratory for an equipment failure analysis. The analysis determined the cause of the component failure to be a latent manufacturing defect. An iron core lamination was slightly out of alignment with the other laminations in the transformer's 'E' core assembly. The slight misalignment created a sharp, thin metal edge that, coincident with existing lamination vibration, slowly cut into and degraded the internal insulation around the coil wire. The internal insulation was found to be cut/worn below the required voltage withstand level resulting in a winding-to-winding fault. The high fault current caused very high temperatures and melting of the copper windings. Due to the relatively small amount of run time (approximately 3000 hours) on the EDG, the insulation degradation developed slowly over a period of approximately 25 years. Manufacturing defects normally manifest as an early failure, however the limited actual in-service energized time of the EDG delayed the appearance of the defect. However, once a coil winding-to-winding fault develops, it is postulated that it grows quickly, resulting in sudden component failure in a relatively short period of time.

Palo Verde licensee corrective actions include the following:

- Adding a preventive maintenance task for thermography of EDG excitation system silicon controlled bridge rectifiers, power diode bridge rectifiers, current transformers, power transformers, and linear reactors. Additionally, performing these new thermography surveys may necessitate a plant modification to install new viewing ports for safely performing thermography in difficult locations similar to the cabinet housing the linear power reactors.

- Using a data recorder to capture various EDG parameters during startup and provide trending for troubleshooting can enhance the licensee's corrective action program.

- Inspecting linear power reactors for signs of defects such as observing splits in the laminated windings of the transformer's 'E' core and by performing surge/meggar testing to detect degrading insulation integrity.

- Periodically replacing some power magnetic components based on service time. Availability of spares for the excitation system components can increase EDG availability.

Other actions to be considered by licensees may include:

- Performing visual inspections for burn marks on the linear power reactors, conductors, cabinet and electrical connections.

- Incorporating into plant maintenance procedures the industry's preventive maintenance recommendations contained in Technical Report/Maintenance Guide for the individual voltage regulator model.

DISCUSSION

This IN describes the failure of a linear power reactor in an EDG voltage regulation system at plant where the licensee’s preventive maintenance program did not address the EDG excitation system magnetic components that can be subject to deterioration with age or time in service. The licensee's preventive maintenance strategy included a visual inspection and cleaning at a frequency of once every three fuel cycles. The visual inspection was non-intrusive and would not reveal latent manufacturing defects. There are no vendor recommendations that specify predictive maintenance to identify degrading magnetic components prior to failure. Thermography, surge testing, or other maintenance practices may reveal a potential fault developing after the insulation sufficiently degrades, but it might not be enough in advance to prevent an equipment failure in-service.

Reviews by the licensee and the NRC revealed past industry experience with degraded voltage regulation magnetic components. However, these prior events did not conduct detailed laboratory analyses to determine the failure mechanisms. In most cases, the failures were attributed to age related degradation. However, the DuPont Nomex insulation material used for the linear reactor coils was found to be rated for an extended life while in service up to 428 degrees Fahrenheit (220 degrees Celsius). In this case, the manufacturing defect was attributed to poor workmanship and assembly techniques during original component construction. The failed component was originally assembled in the 1970s and installed in the 1980s. The defect went undetected until its ultimate failure under loaded conditions. The relatively small amount of run time on the EDGs, over several years, facilitates characterizing these types of defects as age related failures whereas latent component manufacturing defects can actually result in failures earlier than what is their expected service life.

CONTACTS

This IN requires no specific action or written response. Please direct any questions about this matter to the technical contacts listed below or the appropriate Office of Nuclear Reactor Regulation project manager.

/RA/

Timothy J. McGinty, Director
Division of Policy and Rulemaking
Office of Nuclear Reactor Regulation

/RA by MTschiltz for/

Daniel H. Dorman, Director
Division of Fuel Cycle Safety and Safeguards
Office of Nuclear Material Safety and Safeguards

/RA/

Glenn Tracy, Director
Division of Construction Inspection
and Operational Programs
Office of New Reactors

Technical Contacts:

Joseph Bashore
623-393-3737
E-mail: Joseph.Bashore@nrc.gov

Prem Sahay
301-415-8439
email: Prem.Sahay@nrc.gov

Note: NRC generic communications may be found on the NRC public Web site, http://www.nrc.gov, under Electronic Reading Room/Document Collections.

CONTACTS

This IN requires no specific action or written response. Please direct any questions about this matter to the technical contacts listed below or the appropriate Office of Nuclear Reactor Regulation project manager.

/RA/

Timothy J. McGinty, Director
Division of Policy and Rulemaking
Office of Nuclear Reactor Regulation

/RA by MTschiltz for/

Daniel H. Dorman, Director
Division of Fuel Cycle Safety and Safeguards
Office of Nuclear Material Safety and Safeguards

/RA/

Glenn Tracy, Director
Division of Construction Inspection
and Operational Programs
Office of New Reactors

Technical Contacts: Joseph Bashore
623-393-3737
E-mail: Joseph.Bashore@nrc.gov

Prem Sahay
301-415-8439
email: Prem.Sahay@nrc.gov

Note: NRC generic communications may be found on the NRC public Web site, http://www.nrc.gov, under Electronic Reading Room/Document Collections.

ADAMS Accession Number: ML093340392 ME2313

OFFICE	EEEB:DE	Tech Editor	BC:EEB:DE:NRO	BC:EEEB:DE	D:DE	
NAME	PSahay	KAzariah-Kribbs	APal	GWilson	PHiland	
DATE	01/19/2010	12/15/09 email	01/20/2010 email	01/20/2010	01/25/2010	
OFFICE	PGCB:DPR	PGCB:DPR	BC:PGCB:DPR	D:DCIP:NRO	D:FCSS:NMSS	D:DPR
NAME	DBeaulieu	CHawes	MMurphy	GTracy	DDorman (MTschitlz for)	TMcGinty
DATE	01/26/10	01/27/10	01/27/10	02/23/10	02/26/10	02/26/10

OFFICIAL RECORD COPY

UNITED STATES
NUCLEAR REGULATORY COMMISSION
OFFICE OF NUCLEAR REACTOR REGULATION
WASHINGTON, DC 20555-0001

November 1, 2010

NRC INFORMATION NOTICE 2010-23: MALFUNCTIONS OF EMERGENCY DIESEL GENERATOR SPEED SWITCH CIRCUITS

ADDRESSEES

All holders of an operating license or construction permit for a nuclear power reactor issued under Title 10 of the *Code of Federal Regulations,* Part 50, "Domestic Licensing of Production and Utilization Facilities," except those who have permanently ceased operations and have certified that fuel has been permanently removed from the reactor vessel.

PURPOSE

The U.S. Nuclear Regulatory Commission (NRC) is issuing this information notice (IN) to inform addressees about recent examples of malfunctions of emergency diesel generator (EDG) speed switch circuits. The NRC expects that recipients will review the information for applicability to their facilities and consider actions, as appropriate, to avoid similar problems. Suggestions contained in this IN are not NRC requirements; therefore, no specific action or written response is required.

DESCRIPTION OF CIRCUMSTANCES

Wolf Creek Generating Station

On October 22, 2009, with the Wolf Creek Generating Station in a refueling outage, the control room annunciator for the "A" EDG actuated. The licensee took the "A" EDG out of service for troubleshooting. The cause of the event was the actuation of the speed switch in the starting circuit of the "A" EDG because of high alternating current (ac) noise on the direct current (dc) supply circuit of the speed switch. The source of this electrical noise was traced to the annunciator power supply within the EDG gauge board panel. The noise was more than the filtering capacity of the capacitor installed on the dc feed to the speed switch. The licensee replaced the annunciator power supply and the speed switch. It also established a preventive maintenance activity to have the ac ripple voltage measured at the dc supply circuit. Additional information appears in Wolf Creek Generating Station Licensee Event Report 50-482/2009-005, dated December 21, 2009, on the NRC's public Web site in the Agencywide Documents Access and Management System (ADAMS) under Accession No. ML093640041.

San Onofre Nuclear Generating Station

On December 12, 2009, at San Onofre Nuclear Generating Station Unit 3, during the performance of a test required by the technical specifications, the train "A" EDG failed to start because a capacitor failed in one of the two dc-dc converter power supplies for the local panel annunciator. The failed capacitor caused excessive ripple voltage and spiking on the speed switch circuits, causing the speed switch to change state prematurely, preventing the engine from starting. Licensee corrective action included replacing the annunciator power supplies on all the EDGs with more recently manufactured units. Additional information appears in San Onofre Nuclear Generating Station Licensee Event Report 50-362/2009-002, dated February 10, 2010, in ADAMS under Accession No. ML100470689.

DISCUSSION

Licensees are required to maintain EDGs in an operable condition as specified in the technical specifications. The two events described above are recent examples of malfunctions of speed switches on EDGs resulting from noise caused by degraded annunciator power supplies. Industry operating experience during the last 7 years shows approximately 10 additional examples where EDGs were rendered inoperable because of speed switch malfunctions. Three of these events were caused by the inadequate filtering of electrical noise or ripple voltages. The noise can be caused by the age-related degradation of noise-filtering capacitors in the power supplies.

CONTACT

This IN requires no specific action or written response. Please direct any questions about this matter to the technical contacts listed below or the appropriate Office of Nuclear Reactor Regulation (NRR) project manager.

/RA by TQuay for/

Timothy J. McGinty, Director
Division of Policy and Rulemaking
Office of Nuclear Reactor Regulation

Technical Contacts: Vijay Goel, NRR
301-415-3730
E-mail: vijay.goel@nrc.gov

Joseph Giantelli, NRR
301-415-0504
E-mail: joseph.giantelli@nrc.gov

Note: NRC generic communications may be found on the NRC public Web site, http://www.nrc.gov, under Electronic Reading Room/Document Collections.

annunciator. The failed capacitor caused excessive ripple voltage and spiking on the speed switch circuits, causing the speed switch to change state prematurely, preventing the engine from starting. Licensee corrective action included replacing the annunciator power supplies on all the EDGs with more recently manufactured units. Additional information appears in San Onofre Nuclear Generating Station Licensee Event Report 50-362/2009-002, dated February 10, 2010, in ADAMS under Accession No. ML100470689.

DISCUSSION

Licensees are required to maintain EDGs in an operable condition as specified in the technical specifications. The two events described above are recent examples of malfunctions of speed switches on EDGs resulting from noise caused by degraded annunciator power supplies. Industry operating experience during the last 7 years shows approximately 10 additional examples where EDGs were rendered inoperable because of speed switch malfunctions. Three of these events were caused by the inadequate filtering of electrical noise or ripple voltages. The noise can be caused by the age-related degradation of noise-filtering capacitors in the power supplies.

CONTACT

This IN requires no specific action or written response. Please direct any questions about this matter to the technical contacts listed below or the appropriate Office of Nuclear Reactor Regulation (NRR) project manager.

/RA by TQuay for/

Timothy J. McGinty, Director
Division of Policy and Rulemaking
Office of Nuclear Reactor Regulation

Technical Contacts: Vijay Goel, NRR
301-415-3730
E-mail: vijay.goel@nrc.gov

Joseph Giantelli, NRR
301-415-0504
E-mail: joseph.giantelli@nrc.gov

Note: NRC generic communications may be found on the NRC public Web site, http://www.nrc.gov, under Electronic Reading Room/Document Collections.

ADAMS Accession Number: ML102420002 TAC ME4083

OFFICE	DE:EEEB	Tech Editor	DIRS:IOEB	BC:DIRS:IOEB	BC:DE:EEEB
NAME	VGoel	KKribbs	JGiantelli	JThorp	RMathew
DATE	9/23/10	9/10/10 (e-mail)	9/23/10	9/23/10	9/27/10
OFFICE	D:DE	LA:PGCB:NRR	PM:PGCB:NRR	BC:PGCB:NRR	D:DPR:NRR
NAME	PHiland GWilson for	CHawes	DBeaulieu	SRosenberg	TMcGinty (TQuay)
OFFICE	10/26/10	10/27/10	10/27/10	10/28/10	11/01/10

OFFICIAL RECORD COPY

INFORMATION SYSTEMS LABORATORIES

Emergency Diesel Generator Failure Review 1999 - 2001

Final Report
September 14, 2011

Prepared by:
B. Mrowca

Information Systems Laboratories, Inc.
11140 Rockville Pike
Rockville, MD 20852

Introduction

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 was performed to:

- Confirm the baseline reliability values contained in the Mitigation System Performance Index (MSPI) guidance (Nuclear Energy Institute (NEI) 99-02, "Regulatory Assessment Performance Indicator Guideline," Revision 6, October 2009),
- Support the changes in the MSPI EDG failure definitions, and
- Assess the impact on the EDG baseline failure rates that results from including the fuel oil transfer pumps (FOTPs) and related controls within the EDG component boundary.

MSPI Baseline Data

NEI 99-02 provides guidance for the data and calculations used to support the MSPI program.. Included in this guidance are the identification and definition for three modes of EDG failures: Failure to Start, Failure to Load/Run and Failure to Run. Each of these failure modes has an associated baseline reliability value that is used in the MSPI formulation to determine the change in a simplified core damage frequency evaluation resulting from differences in unavailability and unreliability relative to these baseline values.

The baseline values used by the MSPI program are shown in Table 8 of NEI 99-02. These values were developed by Idaho National Laboratory (INL) and can be traced to a paper titled, "Historical perspective on failure rates for US commercial reactor components," [1] dated December 19, 2002, written by Steve Eide (formerly of INL) for *Reliability Engineering & System Safety*. The failure data used in the paper were derived from the Equipment Performance and Information Exchange (EPIX) database contained within Institute of Nuclear Power Operations' (INPO's) Consolidated Data Entry System (CDE).

The reported failure rates shown in Eide's paper were based on failures that occurred during the period of 1999 to 2001. Regrettably, the source data (i.e., specific failure records and success data) used for these failure rates are not available. This lack of data makes it difficult to determine the effect of changes to the scope and definitions of EDG failures on the baseline values. Therefore, a key objective of this current report is to identify and document the EDG failures that are used in the baseline failure rate calculation.

MSPI EDG Failure Definitions

A proposal to revise the EDG failure definitions is documented in Frequently Asked Question (FAQ) 11-08 (available in NRC's Agencywide Documents Access and Management System (ADAMS) at Accession No. ML111450134). Key differences between the current definitions used in NEI 99-02 Revision 6 and the proposed definitions are:

[1] Reliability Engineering and System Safety Volume 80, Issue 2, May 2003, Pages 123-132

- Changes to the transition point between a start and load/run failure where start failure exposure ends when the EDG output breaker receives a signal to close as opposed to the previous requirement where a successful start required reaching rated speed and voltage.

- Changes to the load/run failure definition from the failure to successfully load sequence and run/operate for one hour to the failure to run for one hour after breaker has received a signal to close.

- Clarification of run failure to not require the EDG to be fully loaded and the inclusion of the failure of a FOTP if the pump's failure results in the failure of the EDG to be able to run for 24 hours.

The impact of the treatment of the first run hour was also identified as a potential issue to be resolved in conjunction with the proposed changes in failure definitions[2]. The current practice defined in NEI 99-02, Revision 6, is to include the first hour in the calculation for the EDG run failure rate while failures during this first hour are included in the load/run failure rate.

The primary objective of the failure definition changes is to sharpen the transition points between the three failure modes. A key objective of this report is to determine whether the EDG failure rates reported in NEI 99-02, Table 8, remain valid given the revised failure definitions. The report also addresses the impact of changing the treatment of the first run hour.

Fuel Oil Transfer Pumps

FOTPs are often used in EDG fuel systems to transfer fuel from storage tanks to a local day tank. As part of the current MSPI formulation, FOTPs are not considered to be a monitored component for reliability monitoring within the MSPI Emergency AC performance indicator. An objective of this failure review is to assess the impact of including the FOTPs within the scope of the EDG baseline reliability data.

Approach

This section addresses the approach used to collect and review selected EDG failures and associated success data. In order to meet the stated objectives, all EDG failures that occurred at U.S. commercial nuclear power plants during the MSPI industry baseline period were identified and reviewed. Each failure was assessed as to whether it placed an EDG in a condition to not meet its safety function consistent with the modeling of EDGs in a typical probabilistic risk assessment (PRA). Those failures resulting in the loss of the EDG safety function were considered to be MSPI failures. The failure data identification and review process is described in the *Failure Data* Section below. The associated start demands, load/run demands and run hours, referred to as "success data," were also determined for the same period and for the same set of EDGs. The development of these data is described in the *Success*

[2] FAQ 11-06, MSPI EDG Run Hour reporting, ADAMS Accession Number: ML 110980021, and posted as FAQ 480 on http://www.nrc.gov/NRR/OVERSIGHT/ASSESS/faqs_by_id.pdf)

Data Section below. The resulting failure and success data were used to calculate the failure rates contained within this document, and these rates were then compared against the NEI 99-02 Table 8 values. The assessment of the failure definition changes was accomplished by comparing the failure record categorization between that coded by the industry with the coding determined by this current review. Failures associated with the FOTPs were explicitly identified, and a sensitivity analysis was performed to determine the impact of including these failures within the boundary of the EDGs. A sensitivity analysis was also performed to determine the impact of excluding the first run hour from the run failure rate.

Failure Data

In order to reconstitute the original data and to perform a broad review of the failures that could be candidate contributors to the failure rate for the baseline period, a review was performed using the same data source (EPIX) and the same period (January 1, 1999 through December 31 2001) as that of Steve Eide's original review. Specifically, a copy of the EPIX data source containing data through the 1st quarter of 2010 was used for the review.

To ensure the identification of all applicable records, the scope of review included failure records associated with the EDG systems having a discovery date between January 1, 1999 and December 31, 2001. The Energy Industry Identification System (EIIS) Codes DC, DE and EK were used to identify the EDG-related records because other searchable fields contained plant-specific names and system designators that limited automatic searches. Some non-applicable records were identified and excluded because this approach yielded some records not associated with the EDGs.

Each failure was reviewed against the MSPI failure definitions and categorized by failure mode and cause. Table 1 provides the list of cause categories used in this report.

Table 1
Cause Categories

Failure Cause Category	Description
AAC	The screening process identified 65 failures associated with non-safety-related emergency diesel generators. These failures were coded as "AAC" for Alternate AC power. These failures are not further discussed in this report.
Air Start	Failures related to the air start function.
Breaker	Failures related to breaker operation internal to the breaker.
Control	Failures related to EDG start, load, speed or voltage control. Excludes failures of the output breaker and sequencer failures.
Coolant	Failures associated with water leakage, cooling water valve problems and silting.
Engine	Failures directly related to the mechanical operation of the EDG.

Fuel (Other than transfer)	Failures related to the fuel system including leakage and contamination. Excludes failures associated with the transfer of fuel from storage tanks to day tanks.
Fuel Transfer	Failures of the fuel transfer system including the fuel oil transfer pumps.
Generator	Failures associated with generator operation including field flash and generator excitation. Excludes voltage control, which is address under "Control."
Lube Oil	Failures related to the lube oil system including lube oil pump failures and system leakage failures.
Not Applicable	The failure identification process identified 43 failures of components not related to the EDGs or Alternate AC power. These were all coded as "Not Applicable." These failures are not further discussed in this report.
Operator Error	EDG failures directly caused by operator actions.
Sequencer	Failures related to the sequencing of loads.
Unknown	Failures with an unknown cause.
Ventilation	Failures associated with the ventilation system.

The failures are summarized in Appendix A.

Success Data

The success data used for the calculation of the EDG failure rates were obtained from CDE. The collected data include EDG start and load-run demands and run hours needed to calculate the applicable failure rates for each failure mode. Much of the data are based on licensee estimates with a limited amount of actual performance data. In several cases there were multiple entries of success data reflecting updates of data since the initiation of the MSPI. In all cases, the success data used were those closest in calendar time to the 1999 – 2001 baseline period.

For the failure to run, the impact of including the first load run hour in the total run hours was investigated by calculating the run failure rate with and without the inclusion of the first run hour. This impact was estimated by equating each load/run demand to a run hour.

The success data are listed in Appendix B.

Data Quality

The identified MSPI failures and their associated failure modes are highly dependent on the CDE failure and success data because the assignment of these failure codes was performed using only the available information contained within CDE. Many records contained limited or incomplete information about the operational condition of the EDG at the time of the failure (e.g., EDG loaded, output breaker closed, etc.) and the timing when the failure occurred (e.g., run time following breaker closure). Many records also lacked a complete narrative assessment of the failure's impact. These limitations required the application of considerable judgment by the reviewers of these data and are a source of uncertainty in both the identification of MSPI failures and the assignment of their failure modes.

A review of the initial failure identification and mode assignment was performed by members of the NEI Reactor Oversight Process Task Force. This industry review was done only for the identified MSPI failures and did not include the identification process or a review of the screened failure records. Their review found the classifications to be generally appropriate but identified several failure records that were judged not to be EDG MSPI failures and several where there was a significant possibility that the reported condition did not represent a failure. In response to the review comments, six of the seven failures assessed as not representing a failure were reclassified. The remaining failure, Failure ID 26533, was maintained because it addressed the failure of an FOTP and is included in the proposed revision to the EDG run failure definition. Of the 13 additional failures identified as questionable by the NEI task force members, 5 were removed from the MSPI baseline failures. Table 2 provides a summary of the disposition of each of the 13 failures.

Table 2
NEI Failure Recommendations and NRC/ISL Final Disposition

Number	Failure ID	Description	NEI Task Force Comment	NRC/ISL Disposition
1	2683	With the EDG loaded, the lube oil pump relief valve cycled open and closed, below its 130# setpoint. The lube oil pressure was approximately 85#.	Identified as questionable.	The failure report states that a degraded lube oil pump required replacement and includes no assessment as to whether the EDG would have perform its safety function. This failure is maintained.
2	3099	A fuel oil leak at the fuel oil isolation valve occurred while the DG was being shutdown.	Leak during shutdown cycle. Need more information to determine the potential impact during an emergency demand.	The failure record states that "a fuel oil leak developed and rapidly grew in size, requiring declaring the DG unavailable at 03:00." This failure is maintained.

Number	Failure ID	Description	NEI Task Force Comment	NRC/ISL Disposition
3	6481	Burning odor and smoke came from an EDG control Panel during a surveillance run. The EDG was manually shutdown. A linear reactor in the generator exciter controls was found to be completely functional, except that there was evidence of a grounded overheated location.	Degraded operation, but no failure occurred. Evaluate actual impact.	Failure was coded by licensee as a run failure based on the belief that failure was imminent. This failure is maintained.
4	13786	EDG voltage went to 2KV after starting, then hesitated prior to reaching 4KV as required. Time to reach 4KV exceeded required 10 seconds. The problem was in the field flash circuitry.	The only impact was a slow start time. This should not be counted as a failure.	As the EDG did perform its safety function consistent with that required for a typical PRA and was only delayed for 5 - 6 seconds, this failure has been removed from the MSPI baseline failures.
5	15174	Service Water leak on elbow on heat exchanger tube side bent elbow was found corroded.	This minor condition needs further evaluation to determine the impact, but it would not result in a start failure.	As the leak was characterized as minor and the failure was coded by the licensee as not impacting the EDG, this failure has been removed from the MSPI baseline failures.
6	15228	EDG was recently rebuilt due to extensive damage. During it break-in runs engine had to be shutdown due to high d/p across lube oil strainer indicative of bearing failure. Bearing failure heating caused damage to multiple other components.	Post Maintenance run?	Licensee coded this failure as unavailable, not failed. Therefore, it is assumed that bearing failure is the result of maintenance as failure was discovered during post maintenance testing. This failure has been removed from the MSPI baseline failures.

Number	Failure ID	Description	NEI Task Force Comment	NRC/ISL Disposition
7	15635	Unstable governor output caused DG to hunt and swing during unloaded, loading and unloading operations. The cause was determined to be multifold, including soldered joint connections and HVAC air flow interaction.	See Failure ID 15636. Two independent failures on the same day.	A review of the two failure records (15635 and 15636) confirms that both failures did occur on the same day and were independent. The second failure was associated with exciter diodes and believed to be caused by a voltage transient (independent of the governor maintenance). This failure is maintained.
8	15636	EDG tripped on overspeed due to failed exciter diodes. The failed diodes prevented voltage from developing after field flash was applied.	See Failure ID 15635. Two independent failures on the same day.	See Failure ID 15636. This failure is maintained.
9	16235	Rust scale blocking air start pressure control valves in the air start system caused a failed start attempt on the EDG.	Did this affect both air start subsystems? Are there two subsystems on this DG?	The failure record does indicate that there are two air start systems. It states that "Following the failed start, Operations closed DA31, open DA45, and reset the 86-2 lockout via the pushbutton on C3616. Nothing abnormal was noted in the DA45 side start." This failure has been removed from the MSPI baseline failures.
10	17428	EDG annunciators for "Crankcase Pressure HI" and "DG Auto Start Locked Out" came in, in response to work being performed on the room ventilation dampers. When an HVAC damper failed shut, it caused a vacuum in the room, which actuated the crankcase pressure switch trip.	There was no failed component within the component boundary.	The failure record states that the EDG was in standby and would not have started during the brief interval that the crankcase pressure switch was activated. As this event is the result of maintenance of the ventilation system with EDG performing as designed, the failure has been removed from the MSPI baseline failures.

Number	Failure ID	Description	NEI Task Force Comment	NRC/ISL Disposition
11	20392	EDG failed to respond to voltage regulator manual control during loaded operation. VAR loading dropped without adjustment and would not respond to control board signal adjustment.	Is this a duplicate of Failure ID 20393?	These two failures (20392 and 20393) have different discovery dates. Evidence is insufficient to combine the records. This failure is maintained.
12	20393	EDG failed to respond to voltage regulator manual control during loaded operation. VAR loading dropped without adjustment and would not respond to control board signal adjustment.	Voltage regulator is not used in manual control during emergency start.	The failure record provides no indication as to cause of failing to reach rated voltage. This failure is maintained.
13	20404	EDG experienced spurious annunciation of oil pressure, low water pressure, and overspeed after successful completion of test. A faulted LWD relay was most likely the cause.	Annunciated Failure?	The failure record contains Insufficient information to remove. The licensee coded the failure as erratic output (MSPI-S). This failure is maintained.

Results

A total of 383 functional failure reports from CDE related to emergency and alternative AC power generation were identified and reviewed. Of these failures, 275 were identified as failures related to the EDGs. The remaining 108 screened records were related to alternative AC power sources or other non-EDG related components. Of the 275 failures associated with the EDGs, 137 were assessed as being MSPI failures. In addition, the success data (start demands, load run hours and run hours) were estimated for the 222 EDGs included within the scope of CDE. The results of this review are summarized below:

Table 3
EDG Failure Comparison

Type	Total	Start	Load Run	Run
Number of Failures (including FOTPs)	137	75	42	20
Number of Failures (excluding FOTPs)	135	75	42	18
Success Data		13,772 demands	11,843 demands	26,170 hours
Average (Demands/Hours) per EDG per year		62 demands	53 demands	118 hours
Maximum Likelihood Failure Rate (including FOTPs)		5.45E-03	3.55E-03	7.64E-04
Maximum Likelihood Failure Rate (Excluding FOTPs)		5.45E-03	3.55E-03	6.88E-04
NEI 99-02 Revision 6 Table 8 Values		5.00E-03	3.00E-03	8.00E-04

EDG Run Hour Sensitivity Results

Table 4 summaries the impact of including the first load-run hour in the failure to run calculation. It shows that the exclusion of this hour results in a failure rate value consistent with NEI 99-02, Table 8.

Table 4
EDG Run Hour Sensitivity

Type	Run Including first hour	Run Excluding first hour
Number of Failures (including FOTPs)	20	20
Number of Failures (excluding FOTPs)	18	18
Success Data	38,013 hours	26,170 hours
Average per EDG per year	171 hours	118 hours
Maximum Likelihood Failure Rate (including FOTPs)	5.26E-04	7.64E-04
Maximum Likelihood Failure Rate (Excluding FOTPs)	4.74E-04	6.88E-04

Failure Categories

Table 5 provides a breakdown of the major causes of EDG failures for the 137 identified failures.

Table 5
MSPI Failure Cause Categories (with FOTP failures)

Failure Cause Category	Total	Total MSPI Failures	Failure to Start	Failure to Load Run	Failure to Run	Total MSPI Failure Percentage
Air Start	28	5	5	0	0	4%
Breaker	14	11	2	8	1	8%
Control	89	55	38	14	3	39%
Coolant	21	13	6	4	3	10%
Engine	27	18	7	8	3	13%
Fuel (Other than transfer)	12	7	4	1	2	5%
Fuel Transfer	8	2	0	0	2	1%
Generator	14	10	5	3	2	8%
Lube Oil	21	13	6	3	4	9%
Operator Error	6	1	1	0	0	1%
Sequencer	19	0	0	0	0	0%
Unknown	4	2	1	1	0	1%
Ventilation	12	0	0	0	0	0%
TOTAL	**275**	**137**	**75**	**42**	**20**	**100%**

Conclusions

Baseline Failure Rate Data

This failure data review found that the failure rates contained within NEI 99-02, Table 8 are generally consistent with the data reviewed for this report.

The report did note that failure-to-run is sensitive to whether the run hours include the first hour. This sensitivity is not unexpected because an EDG is often run for a short duration. Based on the information in Table 3, the average run duration per start is less than three hours when both load/run and run hours are considered ((118 hours + 53 load-demands)/62 starts). Although MSPI treats load/run as a demand, it is, by definition, addressing the first hour of EDG operation following breaker closure and is used in this report to estimate the initial run time. If one removes these load/run hours, the estimated average run duration per start is 1/3 less, a substantial reduction. The exclusion of this initial hour from the run failure rate results in a failure rate increase from 5.3E-4 to 7.6E-4 per hour and results in a failure rate that is consistent with NEI 99-02, Table 8.

Failure Definition Changes

Although the review of the baseline failure data identified many differences between the failure modes determined during the review and those indicated by the failure record, it did not appear that the differences were driven by the proposed changes in the EDG failure mode definitions. Table 6 summarizes the noted differences:

Table 6
Failure Determination Differences

Type	Failures determined by this NRC/ISL review	Industry Total	Industry Failure to Start	Industry Failure to Load/Run	Industry Failure to Run	Industry EDG Unaffected
Failure to Start	75	100	66	3	0	6
Failure to Load/Run	42	15	26	12	3	1
Failure to Run	20	11	8	0	8	4
Total	**137**	**126**	**100**	**15**	**11**	**11**

The baseline failure records developed by industry for this time period predate the implementation of the MSPI program and, as such, do not explicitly code the failure records as MSPI failures. Therefore, Table 6 was developed by reviewing the failure mode codes contained within CDE for those failure records identified as MSPI EDG failures by this current review. This comparison approach allows only the assessment of failures that appear to be under-reported and/or miss-categorized, and does not allow for the assessment of whether the review documented in this report failed to identify any MSPI failures.

The first row of Table 6 addresses the failure to start. It shows 75 start failures of the 137 MSPI failures identified during this review. The column titled "Industry Total" shows the total number of failure to starts coded by industry for the same 137 MSPI failures. The fact that 100 is greater than 75 indicates that 25 failures were coded by this review as one of the other two failure modes. The remaining columns show the treatment of the 75 failures by industry. Of the 75 failure to starts, the industry coded 66 as start failures, 3 as load/run failures, 0 as run failures and 6 were identified as having not impact on the EDG. The other rows are similarly formatted.

Given this framework, a total of 11 failures were identified by industry as not being EDG failures. Although it is possible that with additional information some or all of these failures may be found to have not impacted the EDG's safety function, a conclusion of EDG success could not be made based on the available information.

For the records considered to be both failures by this review and the industry, a comparison of failure mode categorization notes significant differences. There are 86 failures (66 start failures + 12 run/load failures + 8 run failures) of the 137 identified MSPI failures that are categorized as having the same failure mode by this review and industry. Excluding the 11 failures coded as not impacting the EDGs, the resulting differences in failure modes is 40 failures including 26 load/run failures identified as start failures by the industry. Of these 26 failures, most appear to be unaffected by the failure definition used. For example, seven of these failures were associated with the EDG output breaker. The failure of the breaker to close is included as part of the load/run failure definition in both versions. However, six of the 27 failures are related to voltage control issues and may have been identified as start failures due to the inclusion of the requirement for achieving required speed and voltage in the current failure to start definition.

Two of the identified failure to run events are associated with the inclusion of the FOTPs and are clearly the result of the proposed change in the failure definition.

Therefore, with the exception of the voltage-related and fuel oil transfer pump failures representing approximately 20% of the mismatched failures, the failure mode differences appear to be driven by other factors.

Fuel Oil Transfer Pumps

The failure review found eight failure reports related to the fuel oil transfer system. Of these eight reports, two were found to be failures to run. The six failures that were evaluated as not impacting the EDGs include:

- 3 events - Day tank level switch out of tolerance (Potentially 3 duplicate records as they occurred at the same plant and involved the same component)
- 2 events – FOTP failed to stop and overflowed the day tank. Pump was manually terminated.
- 1 event – Diesel FOTP cycled intermittently. Appears that fuel flow to day tank was adequate.

The two fuel oil transfer failures included in the failure rate calculation include:

- Gross leakage of the fuel oil transfer valve discharge relief valve such that the pump would not pump to the day tank.
- Malfunction of the FOTP

The inclusion of the FOTPs within the baseline data has minimal impact on the baseline failure rates and provides a resulting failure rate more consistent with NEI 99-02, Table 8.

Appendix A

1999 – 2001 Failures

1999 - 2001 EDG Failures

Failure ID	Recommended EDG Failure Mode	Start	Load	Run	Discovery Date	Industry Code	Start	Load	Run	Category	Failure Description	Impact	Corrective Action	Comment
	137	75	42	20		190	157	18	15	SUBTOTALS				
245	None	0	0	0	3/27/1999	R	0	0	1	Engine	Cylinder leakage appears to be maintenance related as failure occurred on first STP following maintenance	Unknown	Unknown	
309	None	0	0	0	11/25/1999	R	0	0	1	Operator Error	Load level too low as operator did not step through procedure quick enough	EDG tripped on reverse power while shutting down from test run	Procedure revised	
310	None	0	0	0	3/26/2000	R	0	0	1	Operator Error	Tripped on reverse power 86B during SOP-38.0. Insufficient caution for shutdown with minimal load - Procedural inadequacy	EDG tripped on reverse power	Unknown	
343	S	1	0	0	9/12/2000	S	1	0	0	Control	Auto start light was not illuminated. Blown fuse causing auto voltage circuitry to be inoperable	EDG declared inoperable	Light socket and fuse replaced	
604	None	0	0	0	11/13/1999	None	0	0	0	Sequencer	Sequencer Relay HFA Relay 68G4 did not have acceptable continuity	Unknown - declared a FF	Unknown	
621	None	0	0	0	1/17/2000	S	1	0	0	Control	Would not respond to repeated attempts to raise load. Load was at 3.5 MW. Pot had dead spot on pot winding	Condition cleared with no further operator action. Pot later found to have dead spot on winding	Replaced pot	Recommended by NEI review to be removed as a failure as this failure assoicated with the POT would not impact an emergency demand.
809	R	0	0	1	7/1/1999	R	0	0	1	Lube Oil	LO pressure degraded to approximately 33psi (from 75 psi) from a combination of failed bolting and cracked bracket (stub shaft bushing assembly). Discovered as part of the post maintenance testing. A non-manatory May 1972 maintenance bulletin to retrofit with a new design bracket in order to increase strength had not been implemented. Upgrade likely to have been planned in conjunction with turbo charger upgrades at a later date. Failure does not appear to be directly related to the maintenance actions.	EDG was shut down	Unknown	
944	S	1	0	0	1/28/1999	S	1	0	0	Lube Oil	LO AMOT (cast iron) valve flanges were torqued such that the valve body cracked approximately 20 days after the maintenance was performed. Crack resulted in loss of LO.	EDG declared inoperable	Valve replaced and procedure revised	
945	S	1	0	0	1/29/1999	L	0	1	0	Control	Tachometer driven gear coupling tang broke. The tang connects the tachometer shaft to the bevel driven gear. In addition, the bevel drive gear had broken teeth. The bevel drive gear is attached to the governor power take off shaft. The tachometer drive shaft was bent. Failure investigation concluded that the gear mesh engagement was inadequately spaced. This caused excessive forces to be experienced by the tachometer driven gear and shaft. It was also determined that mesh adjustment could be achieved by varying the thickness of the bearing retainer cover gasket, which corrected the problem.	During Manual Slow Speed Start - this failure had little impact on engine operation. Local Panel Tachometer readout was erratic and reading between 0 and 200 RPM, even though the engine was being loaded at 900 RPM. At less than 200 RPM indicated, the standby keep warm engine systems automatically operated. Note: Had the Tachometer malfunctioned during an Auto-Start, the engine would have failed to run.	An undamaged Tachometer Assembly was installed, and the bearing retainer cover gasket thickness was altered to achieve the desired driven gear engagement.	On an actual LOOP, this Tachometer malfunction would have resulted in a failure to start. A slow start bypasses this input.
1006	None	0	0	0	6/11/1999	None	0	0	0	AAC	AACG tripped during a surveillance test due to failure of the speed sensor. The speed sensor signal provides trip logic to the PLC.	EDG tripped	Speed sensor was replaced	Screened as this is a alternative AC generator.
1014	None	0	0	0	9/23/2000	S	1	0	0	Control	Local Regulator Control Lockout Relay malfunctioned such that the Differential Lockout Relay was not bypassed, when taken to "Local." This prevented the Manual control of the voltage regulator, which went to 5kV.	This malfunction would not have prevented automatic operation of the EDG because it is normally aligned in the "Remote" Voltage Regulator position. This condition was identified during a surveillance of the overspeed trip test, which requires the Voltage Regulator to be taken to Local.	The Local Regulator Lockout Relay was replaced and procedures initiated to exercise the contacts periodically.	

1999 - 2001 EDG Failures

Failure ID	Recommended EDG Failure Mode	Start	Load	Run	Discovery Date	Industry Code	Start	Load	Run	Category	Failure Description	Impact	Corrective Action	Comment
1050	None	0	0	0	2/28/2001	L	0	1	0	Control	EDG A was undergoing its monthly surveillance test by paralleling and loading it onto the grid. The Voltage regulator malfunctioned in Speed Droop mode of operation. This caused an underexcited EDG condition. Attempts to control VARS were unsuccessful and the EDG was subsequently unloaded and secured.	The EDG could not be paralleled to the bus while the Voltage Regulator was in Speed Droop mode. The EDG would have automatically provided emergency power to a de-energized bus such as in the case of a LOOP. However, in order to terminate a LOOP, the EDG would have to be taken to Speed Droop in order to transfer load to the offsite source of power. This function would not be available.	The Voltage Regulator was replaced and tested.	EDG will not parallel with an energized source
1180	None	0	0	0	7/11/1999	S	1	0	0	Coolant	Diesel Engine radiator hose broke and leaked all the coolant from the engine.	The Diesel Engine may have run long enough to perform its intended function to provide starting motive force for the SBO Gas Turbine Generator. Therefore, minimal impact was experienced by the radiator hose failure.	The radiator hose was replaced.	
1195	None	0	0	0	1/7/2009	None	0	0	0	AAC	Gas Turbine Generator # 1 failed to start during cold weather testing to prove reliability. Cause was determined to be fuel flow too low due to valve throat diameter.	Gas Turbine was unavailable until ambient temperature rose.	Larger fuel valve was installed.	
1196	None	0	0	0	1/5/2000	S	1	0	0	Air Start	Air dryer found to have a hole rusted through its accumulator section.	EDG 1B was inoperable, although may have been able to start because the air pressure with the compressor running was > 85 psig. Note: The compressor may not be built to accommodate continuous operation.	The defective accumulator was replaced.	
1203	None	0	0	0	2/18/2000	None	0	0	0	AAC	Cooldown Lockout Alarm came in due to an loose RTD wire. This prevented the start of the Gas Turbine Generator.	This failure would have prevented the start of the SBO Gas Turbine Generator.	RTD terminal was tightened and tested.	
1221	None	0	0	0	11/17/2000	None	0	0	0	AAC	Lube Oil Header Temperature RTD Alarm came in due to an loose RTD wire. This prevented the start of the Gas Turbine Generator.	This failure would have prevented the start of the SBO Gas Turbine Generator.	RTD terminal was tightened and tested.	
1239	None	0	0	0	4/25/2001	None	0	0	0	AAC	Malfunctioning Lube Oil Pressure Switch caused erroneous trip input.	Gas Turbine was unavailable until Pressure Switch was replaced.	Replaced Pressure Switch with correct part.	
1300	None	0	0	0	4/6/1999	None	0	0	0	AAC	13.8kV Gas Turbine #2 Output Breaker to Unit 2 failed to close when taken to Close, because it was not fully racked up. This condition was caused by a failed limit switch on the breaker. The damage occurred when racking the breaker up and down for maintenance.	The #2 Gas Turbine was not available for service until the breaker limit switch was repaired.	The operations and maintenance personnel were trained on the event to prevent recurrence. The training and included how to properly adjust the limit switch such that the roller securely fits into the vee notch.	
1425	None	0	0	0	4/14/1999	S	1	0	0	Fuel (Other than transfer)	A drawstring from a spray shield got lodged between fuel pump 8R metering rod and the fuel pump housing. This prevented the rack from going to No-Fuel position when the engine was unloaded.	The EDG ran as expected loaded, but did not go to no-fuel position when shutdown. Although this event did not prevent the engine from raising load, it held the rack open at 50% fuel position. This could have prevented paralleling the engine with offsite power.	All the spray shield drawstrings with removed to prevent further interference.	
1463	R	0	0	1	4/22/2000	R	0	0	1	Fuel (Other than transfer)	Failure of fuel supply line from engine header to the jerk pump (high pressure fuel injection pump) suction	EDG secured via emergency stop	Replace fuel supply hose, inlet elbow and fuel injection pump	
1566	None	0	0	0	1/19/1999	L	0	1	0	Coolant	EDG tripped during loading due to high temperature trip at 198F.	EDG was shut down and declared inoperable.	Adjusted cooling water valve position	Recommended by NEI review to be removed as a failure as this trip is a non-emergency trip that is bypassed during an emergency demand.

1999 - 2001 EDG Failures

Failure ID	Recommended EDG Failure Mode	Start	Load	Run	Discovery Date	Industry Code	Start	Load	Run	Category	Failure Description	Impact	Corrective Action	Comment
1568	None	0	0	0	2/18/1999	S	1	0	0	Engine	EDG tripped on high crankcase pressure trip due to the crankcase pressure trip switch being out of calibration.	EDG tripped from unloaded condition.	Crankcase pressure trip switch was calibrated.	Recommended by NEI review to be removed as a failure as this trip is a non-emergency trip that is bypassed during an emergency demand.
1580	None	0	0	0	6/29/1999	S	1	0	0	Engine	Turbo Air Assist compressor unloader malfunctioned, consequently the compressor would not load.	EDG may have not loaded as required on auto start. Operator nudged unloader and the compressor subsequently loaded. Assumption that turbo boost compressed air is required in order for EDG to start within its required time.	Replaced Unloader with new unit	Likely would not start in rated time -- but would start
1587	None	0	0	0	9/21/1999	None	0	0	0	AAC	Fuel Oil Pumps 2L, 6R, 6L, and 1R leaking fuel excessively such that the engine needed to be secured. Gaskets were not sealed correctly due to relaxation.	SBO EDG was unavailable.	Replaced gasket/tightened fittings	Screened as it is a SBO DG
1589	None	0	0	0	12/13/1999	S	1	0	0	Air Start	EDG M2 Air Start Motor failed to start the EDG in the required time constraints.	EDG may have not loaded as required on auto start. Operator nudged unloader and the compressor subsequently loaded. Assumption that turbo boost compressed air is required in order for EDG to start within its required time.	Replaced M2 Air Start Motor	Believe that the engine would have started without operator intervention
1618	None	0	0	0	5/24/2000	None	0	0	0	Engine	EDG Cooling Fan Drive Gear Box had excess free play, which prompted dismantling and rebuilding.	EDG was unaffected	Rebuilt Drive Gear	
1619	None	0	0	0	5/30/2000	S	1	0	0	Control	"C" Phase Ammeter wiring was historically wired using the wrong gauge wire. Consequently, after a period of time, it broke.	Indication Only was lost	Rewired Ammeter, checked others, and opposite train EDG	
1622	None	0	0	0	8/3/2000	None	0	0	0	AAC	Air Start Motor pinion gear was misaligned with the EDG ring gear causing severe damage	SBO EDG was unavailable.	Repair damaged ring gear and air start motor	Screened as it is a SBO DG
1781	L	0	1	0	2/5/1999	S	1	0	0	Engine	Engine #2 caused the load inbalance by producing 4.6 MW instead of 4.0 MW which Engine #1 was producing. The #2 Engine Fuel Rack Limiter Jack vibrated out of position and required readjustment.	EDG was unavailable	Readjusted and locked down Fuel Rack Jack	
1802	None	0	0	0	5/6/1999	None	0	0	0	AAC	Smoke issued from under the exhaust heat shield of the 0C1 engine when tested. The smoke came from a loose Temperature Element in the exhaust system, which fell out. The engine was secured	EDG was unavailable	Temperature Element was replaced	Screened as it is a SBO DG
1828	S	1	0	0	9/13/1999	S	1	0	0	Control	Operator were unable to control generator output frequency due to Generator Load Sharing and Speed Control Module	EDG was unavailable	The speed control module was replaced, calibrated, and tested	
1956	None	0	0	0	3/8/2000	None	0	0	0	AAC	OC SBO EDG tripped 58 minutes into loaded run due to Cylinder #14 Temperature Element producing a false high temperature system. Failed RTD was cause.	EDG was unavailable	Faulty Temperature Element was replaced	Screened as it is a SBO DG
1987	None	0	0	0	5/10/2000	None	0	0	0	Fuel (Other than transfer)	Engine oil sump was overfilled due to a problem with the insertion of the dipstick. This caused foaming during a test run. The foam caused a low level trip of the EDG within 5 minutes of loaded operation.	EDG was unavailable	Oil level was adjusted	Recommended by NEI review to be removed as a failure as this trip is a non-emergency trip that is bypassed during an emergency demand.
1995	None	0	0	0	4/9/2000	S	1	0	0	Control	1A EDG Output Breaker test failed. Instead of closing in 2 seconds upon reciept of signal, it closed in 245.7 seconds. The fault was traced to the Bus Load Shed Verification Relay.	This failure would not have prevented the 1A EDG from loading Bus 11, but it would have delayed it.	Relay time delay was found to have drifted. EDG taken out of service and relay recalibrated	
1996	None	0	0	0	6/3/2000	None	0	0	0	AAC	Operator changing burnt out light bulb experienced sparks and a short circuit which blew Fuse FUP1A. The "Loss of 125VDC" alarm came in.	DC Power to the SBO EDG was lost, rendering engine unavailable	Light socket and fuse replaced	Screened as it is a SBO DG

1999 - 2001 EDG Failures

Failure ID	Recommended EDG Failure Mode	Start	Load	Run	Discovery Date	Industry Code	Start	Load	Run	Category	Failure Description	Impact	Corrective Action	Comment
2059	L	0	1	0	4/16/2001	S	1	0	0	Control	EDG Radiator Fans were not running with the engine loaded, due to numerous electrical malfunctions including starting relay.	Rendered EDG unavailable	Wiring re-attached to Relay and breaker overcurrent trip settings raised	
2161	None	0	0	0	4/12/1999	S	1	0	0	Control	2A EDG Output Breaker test failed. Instead of closing in 2 seconds upon reciept of signal, it closed in 84. The fault was traced to the Bus Load Shed Verification Relay.	This failure would not have prevented the 2A EDG from loading Bus 21, but it would have delayed it.	Relay time delay was found to have debris in it. EDG taken out of service and relay cleaned and recalibrated	Delayed closure - plant would likely have been protected for all events except large break LOCA
2313	None	0	0	0	7/16/2000	None	0	0	0	Lube Oil	2A EDG had a Lube Oil Cooler leak at a sensing line. It was prudent to secure the engine.	This failure would not have prevented 2A EDG from loading and running.	Engine was secured and oil leak repaired	
2374	None	0	0	0	8/16/2001	None	0	0	0	Control	"2A DG POT VOLT FREQ LO" alarm came in and could not be cleared during test. Engine had to be secured for repair.	After MOT repair it was determined that EDG 2A would have still have been available	Engine was secured and MOT repaired	Believe that on a real event that the EDG would not have been secured.
2453	L	0	1	0	8/31/1999	S	1	0	0	Breaker	The root cause of the diesel generator output breaker tripping was an improper over-current trip set point for the Ampector (solid state trip device) of the breaker. Post trip testing revealed the over-current trip set point for 23 EDG was 3200 amps vs 6000 as intended. This improper setting was caused by the difficulty of setting the Ampector low in its high amp, coarse setting span.	EDG was unavailable during a test demand	Circuit breaker Amptector was recalibrated	
2464	None	0	0	0	9/11/1999	None	0	0	0	AAC	Gas Turbine Generator Starting Diesel failed to start on demand. Diesel air start motor malfunctioned.	Gas Turbine unavailable	starting motor replaced	
2465	None	0	0	0	7/8/1999	None	0	0	0	AAC	Gas Turbine Generator Starting Diesel failed to start due to high jacket water temperature. HVAC Louvers failed to open as required.	Gas Turbine unavailable	Louver motors repaired	
2466	None	0	0	0	7/20/1999	None	0	0	0	AAC	Gas Turbine tripped due to operator error in shifting fuel oil supplies	Gas Turbine unavailable	Valve labelling enhanced	
2467	None	0	0	0	7/16/1999	None	0	0	0	AAC	Tripped on "Combustor #1 Temp Trip" shortly after receiving the teermperature alarm. Alarm was not valid and was found to be due to a loose wire.	Gas Turbine unavailable	Loose wire repaired	
2468	None	0	0	0	7/23/1999	None	0	0	0	AAC	Gas Turbine tripped several times while attempting to start. Investigation identified that Turbine vibration probe #2 wires were detached.	Gas Turbine unavailable	Vibration Probe replaced	
2469	None	0	0	0	7/27/1999	None	0	0	0	AAC	GT2 tripped on high vibration. On restart attempt, however, it tripped on overspeed trip pressure low. Further, a fire started due to a loose bearing cover.	Gas Turbine unavailable	Leak was repaired	
2470	None	0	0	0	7/30/1999	None	0	0	0	AAC	GT2 tripped on high vibration.	Gas Turbine unavailable	Vibration caused by lack of thermal insulation which was replaced	
2474	None	0	0	0	9/13/1999	None	0	0	0	AAC	Gas Turbine turning gear damaged due to lubricating oil sediments. Sediments also found in reduction gears.	Gas Turbine unavailable	Turning gear repaired and new lube oil used	
2475	None	0	0	0	8/24/1999	None	0	0	0	AAC	Gas Turbine 3 Black Start Diesel lube oil check valve to the main reservoir had backflow. This caused insufficient flow in the Diesel Engine if engine is not prelubed prior to starting. The Diesel would have tripped if demanded to start.	Gas Turbine unavailable	Governor logic altered to allow starting with lower lube oil pressure	
2476	None	0	0	0	7/2/1999	None	0	0	0	AAC	GT-3 tripped on sart-up with the Lube Oil Pump breaker opened. The cause of the trip was high current due to high Summer time temperatures and additional loads.	Gas Turbine unavailable	Breaker was replaced with one rated for higher current	
2485	None	0	0	0	12/14/1999	None	0	0	0	AAC	Turning gear failed during test which prevented run of Gas Turbine. Turning gear motor had a blown fuse	Gas Turbine unavailable	Fuse replaced	
2488	None	0	0	0	10/13/1999	None	0	0	0	AAC	Start Air receiver Solenoid Operated Drain Valve malfunctioned. One quart of water found in Receiver.	None	SOV replaced	
2489	None	0	0	0	1/9/2000	None	0	0	0	AAC	GT-1 Air Receiver automatic blowdown valve stuck open, causing low air pressure. Instrument Air Pressure Low alarm was annunciating.	Gas Turbine was unavailable	Air Receiver drain valve was replaced	

1999 - 2001 EDG Failures

Failure ID	Recommended EDG Failure Mode	Start	Load	Run	Discovery Date	Industry Code	Start	Load	Run	Category	Failure Description	Impact	Corrective Action	Comment
2490	None	0	0	0	11/19/1999	None	0	0	0	AAC	GT3 Blackstart Diesel voltage regulator failed. Generator failed to provide power to GT1 and GT2.	GT1 and GT2 were unavailable, which limits availability of SBO power	The Blackstart Diesel motor was rewound and re-installed.	
2491	None	0	0	0	3/10/2000	None	0	0	0	AAC	GT3 Blackstart Diesel was found tripped due to generator stator windings shorting to the armature. Although the generator tripped, the Engine ran until it ran out of fuel because the power supply to the fuel pump was the output of the Generator.	GT3 wouldn't have been available under SBO conditions	The Blackstart Diesel Generator was rewound and re-installed.	
2644	L	0	1	0	1/10/1999	S	1	0	0	Fuel (Other than transfer)	EDG did not load as required due to failure of Fuel Oil Booster Pump losing its prime. The cause was determined to be improper pump and piping configuration, which caused air in-leakage through the pump seal.	EDG was unavailable for power production	Booster pump piping modifications are being evaluated for installation	
2654	S	1	0	0	6/20/1999	S	1	0	0	Engine	EDG had a cracked Cylinder Head which leaked noticeably during unloaded operation. Leak prevented engine from running in its normal parameters and was shutdown.	EDG was unavailable for power production	Cracked cylinder was replaced	
2673	S	1	0	0	10/6/1999	S	1	0	0	Generator	EDG did not load as required due to a shorted diode resulting in loss of generator excitation. The shorted diode in the jacket water pressure permissive is an input into breaker 72-302 field flashing/excitation breaker logic.	EDG was unavailable for power production	The diode was replaced	
2683	R	0	0	1	6/24/1999	S	1	0	0	Lube Oil	With the EDG loaded the Lube Oil Pump P-212B, Relief Valve cycled open and closed, below its 130# setpoint. The Lube Oil Pressure was approximately 85#.	EDG was unavailable for power production	Lube Oil Pump and Relief Valve was replaced	
2706	None	0	0	0	4/4/2000	S	1	0	0	Operator Error	Error in removing Diesel Generator Output Brkr, 152-107, to the 4kV ESF Bus, caused breaker to close and motorize the generator. This caused the Reactor to Trip.	Operations recovered the plant and restored stability to the EDG.	Operations recovered the plant and upgraded procedures and training for 4kV Brkr operations	Maintenance activity - screened
2916	None	0	0	0	2/16/1999	None	0	0	0	Air Start	DG3 starting air compressor intercooler had through wall air leak at the mechanical connection between the high and low pressure heads.	Minimal. Although this rendered Air Start System inoperable until air start headers were cross tied to ensure starting air available to #3 EDG, air start cylinders were charged.	Replaced Air Compressor	
2955	L	0	1	0	5/23/1999	L	0	1	0	Control	DG would not load to greater than 1500 kW instead of the desired 3000 kW. EGA Motor Operated Pot was determined to be malfunctioning.	DG was taken out of service for repair. DG would have been able to pick up Full Load in a LOOP, however may not been able to parallel to restore buses when off-site power returned. A LOOP concurrent with a LOCA may challenge the 1500kW limit.	DG Motor operated POT was repaired	
2961	None	0	0	0	6/9/1999	S	1	0	0	Control	Control Room manual start switch failed	EDG would not start on manual demand from the Control Room.	Control Switch repaired	Screened as it appears that the automatic start function was available and would have functioned.
2989	None	0	0	0	8/22/1999	None	0	0	0	Air Start	Diesel starting air compressor had a leaking intercooer between the first and second stage.	The iar leak did not exceed the capacity of the compressor and the air receiver pressure was maintained.	Control Switch repaired	Screened as it appears that the automatic start function was available and would have functioned.
2996	None	0	0	0	9/7/1999	None	0	0	0	Air Start	DG2 starting air compressor intercooler had leak at the soldered connection between the high pressure outlet and the header.	Minimal. The air start cylinders were charged.	Repaired leak	
2999	None	0	0	0	9/29/1999	None	0	0	0	Air Start	DG1 starting air compressor high pressure RV was found lifted and the compressor running.	Minimal. The air start cylinders were charged.	Replaced Relief Valve	

1999 - 2001 EDG Failures

Failure ID	Recommended EDG Failure Mode	Start	Load	Run	Discovery Date	Industry Code	Start	Load	Run	Category	Failure Description	Impact	Corrective Action	Comment
3005	None	0	0	0	11/14/1999	None	0	0	0	Control	During the performance of 97-AABT1, it was discovered that the 2-E3-AI4-86DB relay was bound up and would not trip. This relay provides protection of the generator against reverse power (32D), an external fault condition (51V), and a loss of excitation (40).	This relay provides protection of the generator against reverse power, an external fault condition, and a loss of excitation. It was found in the reset position. Hence, it would not have prohibited EDG-3 from performing itsdesign function. However, this failed relay exposed the EDG to damage on the occurrence of these events.	Replaced Relay	Not applicable to a real demand.
3047	R	0	0	1	3/3/2000	R	0	0	1	Generator	DG 2 Tripped while supplying power to Bus E-2, due to a failure of the Excitation Transformer.	DG was unavailable	Excitation Transformer was replaced	
3071	None	0	0	0	4/12/2000	None	0	0	0	Lube Oil	DG 4 Aux Lube Oil Pump Brkr was found tripped during operator rounds with the DG secured (standby).	DG was unaffected	Pump motor was tested and found satisfactory. The breaker was replaced.	
3090	None	0	0	0	9/27/2000	None	0	0	0	Air Start	Start Air Compressor had leak on Intercooler leak due to high pressure resulting from failure of compressor suction valves.	Minimal. The air start cylinders were charged.	Air Compressor was replaced	
3099	R	0	0	1	10/17/2000	None	0	0	0	Fuel (Other than transfer)	A Fuel Oil Leak at the fuel oil isolation valve occurred while the DG was being shutdown.	DG became unavailable	1/4" Close nipple was replaced	
3100	None	0	0	0	10/22/2000	None	0	0	0	Air Start	Start Air Compressor had leak on Intercooler leak due to high pressure resulting from failure of compressor suction valves.	Minimal. The air start cylinders were charged.	Air Compressor was replaced	
3103	None	0	0	0	11/27/2000	None	0	0	0	Lube Oil	DG 1 was being secured from a run when it was noticed that the Aux LO Pump was not running normally. At this point in DG operations, the Aux LO Pump should have been supplying pressure. The pump Coupling was damaged.	None	Pump coupling was repaired	
3152	None	0	0	0	3/25/2001	None	0	0	0	Air Start	2-DSA-DG3-CMP-1, Air Start Compressor Brkr was found in the Tripped Condition	None	Motor was placed back in service after meggering and testing	
3590	None	0	0	0	8/23/1999	None	0	0	0	Ventilation	EDG Room Exhaust Fan HVE-17 tripped its breaker, due to faulted motor windings.	EDG B was unavailable	Motor was rewound	Problem associated with a high room temperature after a period of EDG operation.
3948	None	0	0	0	5/19/1999	None	0	0	0	AAC	Fan Trips on Start due to slow Damper Response.	Unknown	Damper was lubricated	Screened as this is an alternative AC DG - Fan is a room cooling fan that would have impacted the DG once the room heats up.
3949	None	0	0	0	5/21/1999	None	0	0	0	AAC	Fans E-85 A-SB and E-85 B-SB will not stay running. Trouble alarm comes in sporadically.	Unknown	Damper was lubricated	Screened as this is an alternative AC DG - Fan is a room cooling fan that would have impacted the DG once the room heats up.
3982	U	0	0	0	11/4/1999	S	1	0	0	Control	Oxidized Motor Operated Potentiometer in the Governor caused the Generator Frequency to drift. This caused the Frequency to stabilize outside of the required 10 Seconds.	EDG B was Inoperable however it would have loaded the ESF bus in the event of LOOP when the Governor is in Isochronous Mode.	Testing cleaned the Potentiometer which functioned normally subsequently.	
4226	S	1	0	0	1/13/2000	S	1	0	0	Control	Loose lead terminal on Governor caused unexpected Frequency Swings when 1A DG was running unloaded.	DG was unavailable	Trouble shooting activities identified the loose governor terminal lead, which was tightened.	
4253	None	0	0	0	2/16/2000	None	0	0	0	Not Applicable	Not EDG related	Not EDG related	Not EDG related	
4374	None	0	0	0	3/15/1999	None	0	0	0	Not Applicable	Not a DG. This is an Emergency Light			
4555	S	1	0	0	2/5/1999	S	1	0	0	Control	DG trouble alarm came in while engine was running unloaded. This alarm can be caused by multiple conditions, many of which were locally in alarm. Additionally, the engine speed spiked for a short time. The cause for all the alarms were from a Power Supply Failure in a control panel.	Failed Power Supply caused 1B DG to be inoperable and unavailable.	Power Supply was replaced with a functioning one	

1999 - 2001 EDG Failures

Failure ID	Recommended EDG Failure Mode	Start	Load	Run	Discovery Date	Industry Code	Start	Load	Run	Category	Failure Description	Impact	Corrective Action	Comment
4655	None	0	0	0	10/5/2000	None	0	0	0	Sequencer	The ESF Sequencer failed to properly sequence the 1A Component Cooling Pump within the surveillance acceptable time of 19.5 to 20.5 seconds. The pump started at 17.4 seconds. This caused other ESF equipment to fail due to the time differential required after the Component Cooling Pump start. The cause may have been relay contacts with a high resistance and a malfunctioning ESF Timer.	The ESF relay contacts were cleaned, and the timer was replaced.	The ESF relay contacts were cleaned, and the timer was replaced.	Screened as related to Sequencer
5062	S	1	0	0	4/12/2000	S	1	0	0	Control	EDG speed oscillated while unloaded. The fuel rack was moving as demanded by the governor. The Governor Solenoid was found to be open-circuited during trouble shooting.	EDG was inoperable and unavailable	Governor was repaired	
5066	None	0	0	0	4/29/2000	None	0	0	0	AAC	U2 SBO DG tripped due to high room tempertures because a room HVAC damper failed to operate. The high temperature caused a loss of control power to the engine. Damper operator was Hydramotor type. Engine was being run for a 24 hour endurance run.	SBO EDG was unavailable 14 hours into the 24 hour test.	Hydramotor was serviced and damper tested	Screened as it's a SBO DG
5145	None	0	0	0	11/26/2000	None	0	0	0	Not Applicable	U2 SBO UPS Inverter failed due to overheating. The overheating was caused by lack of ventilation in that area.	Unknown	Modification planned for increased ventilation to Inverter	
5277	R	0	0	1	3/9/2000	S	1	0	0	Control	EDG electrical output drifted downward while paralleled, due to a governor problem. Missing fasteners caused the Governor Motor to vibrate and change its demand signal downward during 24 hour endurance test.	EDG was inoperable and might not have completed its mission time	Fasteners were installed on the governor housing	
5278	S	1	0	0	3/11/2000	S	1	0	0	Unknown	EDG failed the hot restart test after and endurance run with full load reject. Trouble shooting did not identify a cause.	Engine did not restart to power the ECCS system as required	Trouble shooting activities did not identify a cause. Engine was successfully retested.	
5322	S	1	0	0	6/2/1999	S	1	0	0	Coolant	EDG Jacket Water Cooling system partially drained due to leaking Heat Exchanger Tubes.	Engine would not have run loaded for greater than an hour.	Heat Exchanger tubes repaired	
5324	None	0	0	0	7/4/1999	None	0	0	0	Not Applicable	Not DG related - Circuit Breaker to Non Safety MCC Trip			Circuit breaker failure did not affect EDG
6069	S	1	0	0	7/20/1999	S	1	0	0	Air Start	The air start motr failed to turn over indicating a potential problem with the solenoid	Failure to start	Investigate and repair - no other action stated	
6070	None	0	0	0	6/25/1999	None	0	0	0	AAC	U1 SBO DG tripped on overspeed during testing.	Failure to start	Repaired Overpeed condition	SBO Diesel
6215	None	0	0	0	1/28/2000	None	0	0	0	Ventilation	The EDG Ventilation Control Switch was found in the "Alternate" Feed position instead of the "Normal" Position.	None	Placed switch to "Normal"	
6444	L	0	1	0	10/21/1999	R	0	0	1	Generator	Burning odor came from EDG 12 Control Panel after the completion of a surveillance run. Linear Reactor 1 and the Current Potential Transformer in the Generator Exciter controls, were found to be completely functional, except that there was evidence of a grounded overheated location.	Failure report states that the EDG was manually unloaded and manually shutdown at the end of the surveillance test. Conservatively assumed that the Engine would have failed to Load.	Replaced with new components	

1999 - 2001 EDG Failures

Failure ID	Recommended EDG Failure Mode	Start	Load	Run	Discovery Date	Industry Code	Start	Load	Run	Category	Failure Description	Impact	Corrective Action	Comment
6481	L	0	1	0	5/6/2000	R	0	0	1	Generator	Burning odor and smoke came from EDG 14 Control Panel during a surveillance run. EDG 14 was manually shutdown. Linear Reactor 1 in the Generator Exciter controls, were found to be completely functional, except that there was evidence of a grounded overheated location.	EDG was secured to burnging order	Replaced with new components	
6482	None	0	0	0	5/6/2000	S	1	0	0	Engine	EDG was found with Fuel Rack disconnected from the Governor Actuator. Further, when the Fuel Rack was reconnected, it was found that it would not have been able to achieve full load position.	Limited EDG load to 2750kw during testing.	Reconnected and adjusted governor fuel rack linkage	Maintenance activity - screened
6540	R	0	0	1	3/21/2001	R	0	0	1	Generator	EDG 14 Generator Outboard Bearing failed due to lack of lubrication 11 hours into its 24 hour endurance run.	EDG was unavailable after 11 hours of loaded run	Bearing was replaced and oil sightglass was calibrated.	
6696	L	0	1	0	7/16/1999	L	0	1	0	Control	EDG-2 Voltage Regulator failed which caused the trip of 2DF Emergency Bus. The Voltage Regulator failure caused the Bus offsite feeder to trip open, and erratic EDG voltage caused the operator to manually open the EDG output breaker on to that bus. EDG voltage ultimately went to zero, which instananeously caused the Offsite Power Feeder Breaker to trip on overcurrent.	EDG energized 2DF Emergency Bus but operator force to trip the EDG due to voltage swings.	Voltage Regulator was repaired	
6698	None	0	0	0	12/20/1999	None	0	0	0	Not Applicable	A DC Bus Trouble Alarm for Battery 2-1 Charger came in. The Bus voltage was found to be at 120V. The AC input breaker to the 2-1 Battery Charger was found opened by accident.	Unknown for EDG availability because there may have been enough voltage to start a EDG associated with that DC Bus.	Breaker was closed	This is not a EDG Issue. It was determined that the Battery voltage was 120V. If this DC bus provided control power and field flashing to a EDG, there would be enough voltage present to start the diesel. There is not enough information to
6799	None	0	0	0	5/26/1999	None	0	0	0	Not Applicable	Loss of Emergency Power to 1A Pressurizer Heater Group due to problem with its breaker indication.	This is not an EDG Issue	Breaker Repaired	Not an EDG Issue
6803	L	0	1	0	11/16/1999	S	1	0	0	Engine	D/G Tripped on OverCurrent while loading for Operations Testing. Problems were identified in Fuel Rack Linkages	This is a Failure to Load because the Test was secured prior to one hour of loaded operation.	Fuel Rack Linkages were replaced	
6834	None	0	0	0	7/26/2000	None	0	0	0	Not Applicable	An unexpected trip of Breaker cused loss of power to transformer 1LXI causing loss of blackout power to some loads, not related to EDG.	None - not a EDG	None - Not a EDG	Not an EDG Issue
6842	L	0	1	0	2/6/2001	L	0	1	0	Lube Oil	DG tripped on Lo-Lo Lube Oil Pressure due to instrument slow response. The instrument line had sludge buildup restricting flow. The actual lube oil pressure was always above the trip setpoint.	DG tripped during manual loading	Oil Pressure Instrument Line was flushed	
6846	R	0	0	1	11/10/2000	None	0	0	0	Control	Smoke came from 1B D/G Control Panel during a test run. The D/G was carrying the emergency bus without being paralleled. The Voltage Regulator 3 Phase Power Potential Transformer was faulted.	1B D/G was secured from its loaded run, however it is unknown if it was tripped in less than 1 hour.	Replaced Voltage Regulator	
6965	L	0	1	0	2/7/2000	R	0	0	1	Breaker	DG Output Breaker Closing Coil malfunctioned such that it would not close when testing DG.	DG was inoperable since the Breaker was last closed on 2/7/00 (22 Days). The Breaker Failure prevented the DG from Loading.	Repaired Closing Coil.	
6972	None	0	0	0	5/10/2000	None	0	0	0	Sequencer	DG 2A Sequencer was found Locked in the Reset position and would not actuate on a safety signal.	This is a Sequencer problem where it would prevent the sequenced loading of equipment after D/G Breaker Closure	The D/G 2A Load Sequencer Timer was replaced with a new design	This is a Sequencer issue

1999 - 2001 EDG Failures

Failure ID	Recommended EDG Failure Mode	Start	Load	Run	Discovery Date	Industry Code	Start	Load	Run	Category	Failure Description	Impact	Corrective Action	Comment
7055	None	0	0	0	1/28/1999	None	0	0	0	AAC	The SSF D/G Output Breaker tripped while carrying 700kW of load during paralleled testing. A failed Exciter Diode caused on Overcurrent condition across the Breaker which tripped it.	The Breaker tripped after one hour of loaded operation, however the SSF DG is not Safety-Related.	The Exciter Diode was replaced	The SSF DG supports Safe Shutdown in accordance with Appendix "R"
7061	L	0	1	0	10/2/1999	S	1	0	0	Engine	DG experienced high exhaust temperatures on number 4 Left Cylinder accompanied by noise. Hydraulic cylinder required replacing. Subsequent testing resulted in replacing Exhaust Valve Insert, which was fractured.	DG was shutdown after being loaded for 15 minutes.	Cylinder was rebuilt	
7079	None	0	0	0	11/26/2000	None	0	0	0	AAC	The SSF DG Alarm "600 V System Ground" annunciated. The DG was found with Radiator empty. The Ground alarm indicated high fluid level in the DG Room Sump Area.	SSF DG was unavailable	Holes in the Jacket Water Heater Body and Cooling System were repaired.	The SSF DG supports Safe Shutdown in accordance with Appendix "R"
7217	None	0	0	0	1/10/2000	None	0	0	0	Not Applicable	Hydroelectric Generator Breaker failed	Hydroelectric Generator was unavailable.	Breaker Repaired	This is a Hydroelectric Dam
7240	None	0	0	0	6/8/1999	None	0	0	0	Not Applicable	"Battery Charger Trouble" and "DC Volts Low" Alarms annunciated for the SSF system. Loose lugs caused erratic float voltages to occur.	SSF Standby Battery Charger has no effect on Emergency Diesel Generators	Terminal Lugs repaired	SSF supports Safe Shutdown in accordance with Appendix "R"
7242	None	0	0	0	7/12/1999	None	0	0	0	Not Applicable	SSF Battery Charger Amps dropped to 0 while output voltage dropped to 120V. Soon after, the Charger output returned to normal.	SSF Standby Battery Charger has no effect on Emergency Diesel Generators	None	SSF supports Safe Shutdown in accordance with Appendix "R"
7257	None	0	0	0	8/20/2000	None	0	0	0	Not Applicable	DC Low Voltage Alarm Annunciated in the SSF. Trouble shooting activities determined the problems.	None	Repaired battery cells with low specific gravity.	
7258	None	0	0	0	10/5/1999	None	0	0	0	AAC	Combustion Turbine problem	None	None	
7275	None	0	0	0	6/26/2000	None	0	0	0	Not Applicable	Hydroelectric Generator Breaker failed	Unavailable	Repair Breaker	Hydroelectric Generator
7279	None	0	0	0	1/14/2000	None	0	0	0	Not Applicable	Hydroelectric Generator Breaker failed	Unavailable	Repair Breaker	Hydroelectric Generator
7286	None	0	0	0	9/13/1999	None	0	0	0	Not Applicable	Breaker Failed Offsite Power Supply	Unavailable	Repair Breaker	Offsite Power Supply
7287	None	0	0	0	9/22/1999	None	0	0	0	Not Applicable	Hydroelectric Generator Breaker failed	Unavailable	Repair Breaker	Hydroelectric Generator
7289	None	0	0	0	2/3/2000	None	0	0	0	Not Applicable	Hydroelectric Generator Breaker failed	Unavailable	Repair Breaker	Hydroelectric Generator
7588	None	0	0	0	9/1/1999	S	1	0	0	Coolant	EGDG-1B had a leak that developed in the Jacket Coolant line, during a 2 hour loaded run.	None because the leakage was stopped while the engine was in operation.	Replaced clamp on jacket water line. Clamp was tightened while the engine was loaded.	The test appeared to be completed with the leakage present. This is not a failure to start because the Loaded Run was completed successfully.
7629	None	0	0	0	1/5/2000	S	1	0	0	Engine	Radiator Fan Clutch was hot enough to burn the paint off the Clutch Housing. Condition exists when engine is run in Slow Speed at less than 500 RPM for an extended time. Slow Speed starting is a practice used to minimize wear on engines during testing, however, it raises the wear on the Clutch.	None. The test was completed satisfactorilly. The engine would have run and loaded normally if it were in fast speed or automatic operation modes.	Operations with engine less than 500 RPM was precluded by procedure	

1999 - 2001 EDG Failures

Failure ID	Recommended EDG Failure Mode	Start	Load	Run	Discovery Date	Industry Code	Start	Load	Run	Category	Failure Description	Impact	Corrective Action	Comment
7695	S	1	0	0	8/30/1999	S	1	0	0	Control	The B Battery Ground that was detected coincidentally with the loaded test run of EGDG-1B was localized to an Amphenol Connector on the DG Governor. Amphenol connector started to smoke when energized.	DG Test was suspended apparently prior to loading generator.	Connections were repaired	
7718	S	1	0	0	7/5/2001	S	1	0	0	Fuel (Other than transfer)	EDG failure due to loss of Fuel Oil Header Prime.	EDG would did not start and would not have been available.	Cause of Fuel Prime loss was identified and corrected.	
7834	None	0	0	0	9/16/1999	L	0	1	0	Control	EDG 1A failed to start in the 10 second time limit as required. It started however, in 10.4 seconds and was declared Out of Service. Troubleshooting activities concluded that the Woodward Governor needed replacement.	None. Slow Start would not have affected LOOP Mitigation.	Replace Governor with new model.	
7846	None	0	0	0	6/29/2000	S	1	0	0	Unknown	EDG 1A failed to reach 60 Hz within the required 10 second time limit. It started however, in 10.29 and 10.59 seconds and was declared Out of Service.	None.	Unknown	
7876	S	1	0	0	5/22/2001	S	1	0	0	Coolant	EDG developed a serious radiator leak requiring immediate shutdown.	EDG was shutdown and deemed unavailable.	Radiator repaired	
7877	L	0	1	0	6/11/2001	S	1	0	0	Coolant	EDG developed a serious radiator leak requiring immediate shutdown.	EDG was unavailable less than 1 hour into the loaded run	Radiator repaired	Report states that the Engine was Unloaded and Stopped
7884	S	1	0	0	7/2/2001	S	1	0	0	Air Start	Air Start System Air Flasks Check Valve was leaking such that starting air pressure could not be maintained above the required limit.	EDG would not have been able to start if demanded.	Check valve was repaired	
8010	S	1	0	0	7/20/2000	S	1	0	0	Control	A failed Rectifier Diode prevented the EDG Voltage and Frequency to stabilize while attempting to parallel the Generator on the Safety Bus.	EDG 2B would not have been able to provide reliable power to the Emergency Bus	Diode was replaced	
8136	R	0	0	1	2/26/2000	R	0	0	1	Control	The ITD Time delay relay associated with the EDG governor failed causing a reverse power lockout and subsequent idling of the EDG.	EDG would not have remained loaded.	ITD Coil was failure tested and replaced	Assumed that the EDG was loaded for greater than minutes prior to opening.
8153	S	1	0	0	8/16/2000	S	1	0	0	Control	EDG Speed Control failed to control RPM from a Normal Start demand. Further, the EDG failed to Stop from the Control Room Push Button. The electronic section of the Governor had failed and defaulted to the mechanical section of the Governor.	EDG failed to start within normal parameters.	Capacitors and other electronic components were replaced.	
8212	None	0	0	0	7/28/1999	None	0	0	0	Breaker	Failure of Breaker during testing did not affect EDG operation	None	Breaker Repaired	
8214	S	1	0	0	10/24/1999	S	1	0	0	Fuel (Other than transfer)	EDG Trouble Alarm annunciated for "EDG Not Ready for Emergency Start" and other similar conditions. Fuse Holders were found to be loose and non-conductive. This affected the DC Fuel Oil Pump.	Engine may not have started reliably	Fuse Clip holders replaced	
8399	R	0	0	1	1/29/2000	R	0	0	1	Engine	EDG was manually tripped during Maintenance run due to #4L Link Pin Bushing damage which caused physical damage and vibrations. Engine ran for greater than 1 hour.	Engine would not have run loaded for for continued operation.	Link Pins and bearing supports repaired	This condition was unrelated to the planned maintenance on the EDG.
8416	R	0	0	1	3/23/2001	R	0	0	1	Lube Oil	An Oil Leak on the Turbocharger Lube Oil Piping required that EDG 2B be shutdown prior to the completion of the 24 hour run.	Engine was secured after being loaded for greater than 1 hour.	Leak was repaired	

1999 - 2001 EDG Failures

Failure ID	Recommended EDG Failure Mode	Start	Load	Run	Discovery Date	Industry Code	Start	Load	Run	Category	Failure Description	Impact	Corrective Action	Comment
8422	None	0	0	0	4/26/2001	S	1	0	0	Generator	A malfunction of the Field Flashing circuit caused the DG start time to Voltage and Frequency to be delayed to 13 to 15 seconds beyond the normal 11.4 seconds. DG was undergoing Post Rework Functional Test Run at the time.	Engine was not able to be loaded. Had there been a LOOP demand, the breaker would have closed in and the sequencer actuated the loads appropriately.	Field flashing circuit repaired	
8453	S	1	0	0	1/17/1999	None	0	0	0	Control	"L.O. Temp Hi/Lo, Jacket Temp Hi/Lo Crankcase Press Hi/Lo" Alarm annunciated because the Lube Oil and Jacket Coolant Pumps were not running as required. Although the Breaker Door Handle/Switch indicated that the Breaker for these Loads were not tripped, the breaker was found to be tripped.	Engine may not have started reliably	Breaker door was repaired	
8508	None	0	0	0	1/18/1999	None	0	0	0	Ventilation	DG Room Louver and Room Fan Switches were found in Off Position.	Had DG been required to run, the room temperature would have most likely caused the DG to trip after 1 hour of loaded operation, however the most conservative temperature of 95 F could overheat the room in as little as 19 minutes.	Switches were taken to correct position and placards placed as operator aids.	If outside air temperature was 95 F, then the engine could trip in as little as 19 minutes, however, it would most likely last for at least 2 hours.
8535	S	1	0	0	8/21/1999	S	1	0	0	Control	"L.O. Temp Hi/Lo, Jacket Temp Hi/Lo Crankcase Press Hi/Lo" Alarm annunciated because the Standby Lube Oil Pump and Heater were not running as required. Pump and Heater was restarted locally and alarm cleared.	Engine may not have started reliably	Pump and Heater was restarted locally	
8999	None	0	0	0	6/13/1999	None	0	0	0	AAC	SBO Diesel Cooling Water Supply Isolation Valve would not open as required to admit cooling water.	Engine may not have started reliably	Valve operator was repaired.	SBO Diesel
9098	S	1	0	0	5/5/2001	S	1	0	0	Lube Oil	"LOW LUBE OIL TEMPERATURE" Alarm annunciated because the LO Standby Pump was found not running as required. The pump tripped on high motor current because it was mechanically bound	Engine may not have started reliably	Standby LO Pump was rebuilt	
9216	None	0	0	0	4/18/1999	None	0	0	0	Not Applicable	Manual Initiation Section Feeder Breaker ACB04 tripped and Division III DG closed and energized the bus.	This is not a Diesel Generator Malfunction, the DG functioned as designed.	None	This is not a EDG Issue.
9220	S	1	0	0	7/14/1999	S	1	0	0	Control	Tachometer failed to indicate Div 1 D/G speed change when starting engine.	This condition would have prevented the DG from starting and loading.	Power Supplies for the Tachometer was replaced.	
9276	L	0	1	0	2/8/2001	None	0	0	0	Engine	The DIV II DG Tripped during a loaded run due to a fault. The Air Inlet valve inadvertently closed causing the engine to trip.	DG Tripped less than one hour after synchronising to the bus	Air Inlet Valve and Actuator repaired	
9387	None	0	0	0	4/16/1999	None	0	0	0	AAC	TSC D/G Radiator Fan Failed during attempt to start engine.	Engine would not have been able to run without the radiator.	Radiatiator Fan repaired	This is a TSC DG, not a Safety Related DG
9411	None	0	0	0	4/10/1999	None	0	0	0	Sequencer	Loss of Sequencer Power Supply rendered it inoperable	Sequencer would not have been available to sequence the loads onto the bus	Replaced Power Supply	This is a Sequencer issue
9416	None	0	0	0	9/2/1999	None	0	0	0	AAC	BOP DG tripped while attempting to start because of operator error. Operator overranged the voltage regulator	BOP DG would have to be re-started	Operator Training	BOP Generator is not a Safety Related DG

1999 - 2001 EDG Failures

Failure ID	Recommended EDG Failure Mode	Start	Load	Run	Discovery Date	Industry Code	Start	Load	Run	Category	Failure Description	Impact	Corrective Action	Comment
9434	None	0	0	0	7/29/1999	None	0	0	0	Sequencer	Failed to operate on Demand	Sequencer would not have been available to sequence the loads onto the bus	Unknown	This is a Sequencer issue
9439	None	0	0	0	2/15/2000	None	0	0	0	AAC	TSC DG Failed to start due to Low Battery Voltage	Capability to start and generate electrical power was lost	Batteries replaced	This is a TSC DG, not a Safety Related DG
9454	None	0	0	0	3/13/2000	None	0	0	0	AAC	TSC DG Differential Lockout Relay discovered Tripped with engine secured.	TSC Diesel would not have been available until Breaker Trip was reset	Trouble shooting and reset was successful	This is a TSC DG, not a Safety Related DG
9465	None	0	0	0	4/17/2000	None	0	0	0	AAC	BOP DG Output Brkr failed to close due to a blown fuse in the breaker control power circuit	BOP DG would have not been able to provide power to the BOP bus	Fuse was replaced	BOP Generator is not a Safety Related DG
9498	None	0	0	0	8/14/2000	S	1	0	0	Lube Oil	Lube Oil sampling concluded that was Fuel Oil contamination from leaky injectors.	Engine would have sustained damage after 2 days of loaded run.	Replaced all fuel injectors	This is a TSC DG, not a Safety Related DG
9684	S	1	0	0	3/4/1999	S	1	0	0	Lube Oil	STBY DG 21 Lube Oil Circ Pump did not Auto Start Following Surveillance Testing.	Condition could have affected the next start, however the condition was identified	Replaced starting relay	
9715	None	0	0	0	10/19/1999	None	0	0	0	AAC	SBDG Voltage Regulator failed causing output breaker.	SBDG was loaded for under one hour.	Voltage Regulator was repaired	
9740	None	0	0	0	5/15/2000	None	0	0	0	AAC	TSC DG failed to start due to Control Power Supply Capacitor failure.	Engine wouldn't start	Capacitors and other electronic components were replaced.	TSC Engine
9753	None	0	0	0	5/15/2000	None	0	0	0	AAC	TSC DG failed to start due to loss of Control Power Supply because a battery terminal cable was loose.	Engine wouldn't start	Battery cable tightened	TSC Engine
9759	None	0	0	0	7/3/2000	None	0	0	0	AAC	BOP DG Output Brkr Tripped open immediately after closing due to loose Trip Latch that rotated freely on its shaft.	BOP DG was unavailable for loaded operation	Set screw on Trip Shaft to Trip Paddle tightened	BOP Generator is not a Safety Related DG
9766	None	0	0	0	10/28/2000	None	0	0	0	AAC	BOP DG Output Brkr Tripped open because Closing Solenoid was Sticking. The DG was loaded briefly	BOP DG was unavailable for loaded operation	Closing Coil Solenoid was replaced	BOP Generator is not a Safety Related DG
9767	None	0	0	0	10/23/2000	None	0	0	0	AAC	BOP DG Radiator Overflowed causing Hi-Temperature Trip. Leakage was from Cylinder Freeze Seals and Jacket Water Heaters.	Engine tripped from Loaded condition in less than 1 hour. Engine was not readily available for restart	Leak was repaired	BOP Generator is not a Safety Related DG
9861	None	0	0	0	4/25/1999	None	0	0	0	Sequencer	Load Shedding Relay for Bus 1A3 failed its Continuity Check during Surveillance Testing.	Although this is not a DG malfunction, it would have prevented automatic Breaker operation to energize Bus 1A3 in case of a LOOP. This malfunction is associated with sequencer operation.	Load Shedding Relay contacts were cleaned.	Load Shedding Relay is not a DG Malfunction - sequencer problem
9891	None	0	0	0	8/7/1999	None	0	0	0	Fuel Transfer	EDG Day Tank level switch for Fuel Oil Transfer Pump failed a surveillance where it should have pumped fuel. Instead of the pump filling the Day Tank to 55", it stopped running at 50". The tolerance is + or - 3".	None. This is not a DG malfunction as the Day Tank had adequate level to run the DG.	Level Switch was calibrated.	
9911	None	0	0	0	8/7/1999	None	0	0	0	Fuel Transfer	EDG Day Tank level switch for Fuel Oil Transfer Pump failed a surveillance where it should have pumped fuel. Instead of the pump filling the Day Tank to 55", it stopped running at 50". The tolerance is + or - 3".	None. This is not a DG malfunction as the Day Tank had adequate level to run the DG.	Level Switch was calibrated.	
9930	None	0	0	0	7/8/1999	None	0	0	0	Fuel Transfer	EDG Day Tank level switch for Fuel Oil Transfer Pump failed a surveillance where it should have pumped fuel. Instead of the pump filling the Day Tank to 55", it stopped running at 50". The tolerance is + or - 3".	None. This is not a DG malfunction as the Day Tank had adequate level to run the DG.	Level Switch was calibrated.	

1999 - 2001 EDG Failures

Failure ID	Recommended EDG Failure Mode	Start	Load	Run	Discovery Date	Industry Code	Start	Load	Run	Category	Failure Description	Impact	Corrective Action	Comment
10217	None	0	0	0	2/26/2001	S	1	0	0	Air Start	AB2 DG Starting Air Compressor 2nd Stage RV was stuck open, causing the Air Start Receivers to blow down to 216# instead of 226#. The pressure was maintained because the Air Start Compressors were cross-connected.	None. The minimum required Air Start Receiver pressure is 200#.	Relief Valve was replaced and Compressor 2 was placed in service	Had no effect on DG availability.
10537	None	0	0	0	3/13/2001	None	0	0	0	Air Start	Air Receiver Safety Valve 2-SV-78-AB2 leaking allowing pressure to go to 220#. Normal operating pressure range is 220-240#. "DG2AB Compressor Air Receiver Pressure Low" Alarm annunciator in the control room.	None. The backup Air Receiver was intact and maintaining full pressure and the affected air receiver still had normal operational pressure	Relief Valve was replaced.	Had no effect on DG availability.
10543	None	0	0	0	4/18/2001	S	1	0	0	Air Start	Air Start Compressor Safety Valve 2-SV-81-CD2 failed open. Air Compressor became unavailable.	CD EDG was not available because it is not certain whether there alternative compressed air sources were available. Likely alternate air available - assumed to be no impact.	Relief Valve was replaced.	
10920	None	0	0	0	8/9/1999	None	0	0	0	Fuel (Other than transfer)	A Fuel Oil leak on DG1B sprayed fuel into the Engine Crankcase where it diluted the Lube Oil to greater than 5.7%. This is over the specification allowed for continued operation.	The licensee determined that DG1B would have been available for 7 day continuous operation and beyond.	Fuel Oil Leak repaired, oil replaced	
11004	S	1	0	0	2/12/1999	S	1	0	0	Generator	A loose diode on Div III Generator Exciter was found during inspection.	Generator may have been unavailable to provide power to the bus	Diode was re-torqued to proper specifications	
11010	S	1	0	0	1/26/1999	None	0	0	0	Control	Three Relays were found outside their time delay range specifications. The Relays were Field Flash, Cranking Timer, and Jog Delay.	Engine may not have started reliably	Time delays for the relays were calibrated	
11022	S	1	0	0	3/7/1999	S	1	0	0	Air Start	DG failed to start when 2 out of 3 Air Start Motors failed to engage when demanded. Problem with Air Start Solenoids prevented Air Start Motors from Engaging as required.	DG tripped after the 10 second time delay logic determined that engine was not running	Air Start Solenoids for the Air Start Motors were replaced	
11035	None	0	0	0	4/20/1999	None	0	0	0	Breaker	DG 1A Circuit Brkr failed to Close in response to it's handswitch position when clearing a Tag Out. It is unknown what the Circuit Breaker Load was. Brkr is a Molded Case breaker	Unknown	Breaker was replaced	
11086	None	0	0	0	10/26/1999	None	0	0	0	Control	A Portion of DG 1C Hi-Temperature Shutdown Switch Sealing material was missing. There was no leakage. Condition was identified during routine Switch Calibration.	None. There was no leakage associated with the missing portion of the sealant around the stem of the Temperature Switch. Further, The Hi-Temperature Trip is bypassed on LOCA.	Switch was re-sealed.	
11130	None	0	0	0	2/28/2000	S	1	0	0	Operator Error	Div 3 DG 1C was paralleled to its associated bus Out of Phase due to a failed Synchscope and operator error	DG 1C Output Brkr Tripped after closing and engine removed from service to check for damage. Severe damage resulted from the Out of Phase operations. Operator error associated with test activity, not consider a failure.	Replaced Generator, Turbocharger, and Synchscope	
11184	None	0	0	0	8/31/2000	S	1	0	0	Control	DG 1C Fire Protection Panel Test resulted in Failure of Revolving Light to stop when Reset was Pressed.	None. Engine would not have been affected by this malfunction	Replaced Relay in Fire Protection Panel	
11584	None	0	0	0	1/12/1999	S	1	0	0	Coolant	EG 1A Service Water Bypass around A EDG Heat Exchanger Outlet Valve. Leak was characterized as a pinhole leak	EG 1A is inoperable but would have been available	Repaired leak	This leak had no effect on EG 1A availability. There could have been some seismic degradation which would required analysis

1999 - 2001 EDG Failures

Failure ID	Recommended EDG Failure Mode	Start	Load	Run	Discovery Date	Industry Code	Start	Load	Run	Category	Failure Description	Impact	Corrective Action	Comment
11631	None	0	0	0	1/4/2000	None	0	0	0	AAC	Failed Battery in SBO DG UPS caused SBO DG unavailability. Condition identified during routine check of system.	SBO DG unavailable	Replaced failed battery	SBO Diesel
11632	None	0	0	0	6/12/2000	None	0	0	0	AAC	SBO DG Enclosure Air Conditioning unit found to have a failed 24 VDC transformer that prevented the Temperature Control Function of the HVAC unit	SBO DG was unaffected because alarm function allowed compensatory actions to be taken.	Replaced transformer	SBO Diesel
11639	None	0	0	0	10/24/2000	None	0	0	0	AAC	SBO Computer Trouble Alarm annunciated, indicated that SBO DG was unavailable.	SBO DG unavailable	Repaired cause of Computer Trouble Alarm	SBO Diesel
11789	None	0	0	0	7/6/1999	None	0	0	0	Ventilation	EDG 103 Rollup Door would not function to Close as demanded by the local pushbutton station. The door was opened beyond the limit permitted by Security, which rendered it inoperable. Due to the room temperature, DG room ventilation fans started, which placed too much force against the Roll Up doors to allow movement.	None. Operator secured fan and closed the Roll Up Door. There was no impact.	Signs describing operation of Roll Up Doors with ventilation configuration were placed.	TS Action Statements were applicable for 2-3 Minutes
11796	S	1	0	0	9/18/1999	S	1	0	0	Generator	Bad Fuse connections caused EDG 103 Voltage Regulator to excite the Generator to only 3100 Volts instead of the 4100 Volts required.	EDG 103 was unavailable to provide power to its associated bus as required.	Fuses and Fuse Holders were replaced	
12174	None	0	0	0	2/8/2000	None	0	0	0	Not Applicable	None. This Breaker Failure is applicable only to the RHR Pump related to the Load Shed Logic	None for EDG	Repaired Aux Switch	This condition was unrelated to the EDG
12175	None	0	0	0	1/25/2000	None	0	0	0	Sequencer	Undervoltage Relay for Switch Gear 101 did not reset during testing.	None for EDG, the failure affects Sequencer operation	Replaced Relay	This is a Sequencer issue
12180	None	0	0	0	2/23/2000	None	0	0	0	Sequencer	Div 1 Emergency Switchgear Test Light failed to identify that Undervoltage Relay was functioning correctly.	None for EDG, the failure affects Sequencer operation	Replaced Relay	This is a Sequencer issue
12187	L	0	1	0	3/15/2000	S	1	0	0	Control	Div 1 DG was started for test when Voltage went to over 5kV instead of 4kV. A mispositioned Potential Transformer Fuse Carriage was discovered that caused the anomaly. The DG was tripped which resulted in a Dead Bus on SW101. Breaker was closed in on the bus.	DG was unavailable	Repaired PT assembly	
12408	None	0	0	0	6/21/1999	None	0	0	0	Control	DG-TI-3150, D Cylinder and Exhaust Temperature TI was out of calibration as determined by routine PM. There was no change in indication with manually input variable signal.	None. Although EDG may rely on this TI as trip input, it appears that the temperature was failed below trip setpoint.	Replaced TI Assembly	There is no mention that the instrument output failed high or above trip setpoint, therefore the DG would not have tripped on this condition.
12544	None	0	0	0	4/16/1999	None	0	0	0	Not Applicable	Portable Diesel Oil Pump Operability Test failed because the gas tank was empty and the carburator needle valve was closed.	None. This is not a DG malfunction as the Day Tank had adequate level to run the DG.	Filled gas tank and realigned needle valve	This is not an installed Fuel Oil Pump and does not affect EDG operation.
12652	R	0	0	1	11/25/1999	R	0	0	1	Coolant	DG tripped on High Crankcase Pressure during test run. Coolant leaking into the Crankcase through failed Lube Oil Cooler Welds vaporized causing high pressure.	Engine tripped from Loaded condition in greater than 1 hour. Engine was not readily available for restart	Lube Oil Cooler weld leaks repaired and coolant evacuated from crankcase	

1999 - 2001 EDG Failures

Failure ID	Recommended EDG Failure Mode	Start	Load	Run	Discovery Date	Industry Code	Start	Load	Run	Category	Failure Description	Impact	Corrective Action	Comment
12653	None	0	0	0	12/22/1999	None	0	0	0	AAC	Return to service test run Non-Safeguards DG tripped on Reverse Current due to a dirty Rheostat Motor. Diesel tripped on Reverse Current.	DG Tripped less than one hour after synchronising to the bus	Rheostat motor was cleaned and loose wiring repaired	This is not a Safety-Related DG
12700	S	1	0	0	11/18/1999	S	1	0	0	Engine	DG Surveillance Test aborted due to increase in Crankcase Pressure. The Crankcase Breather had a flow restriction and the Oil Level in the Sump was higher than normal. Both conditions contributed to high pressure.	DG was unavailable until corrective actions taken. DG was not loaded at the time.	Crankcase Breather Tube cleaned and oil level adjusted	
12701	None	0	0	0	10/10/1999	S	1	0	0	Control	D6 DG failed to start and load within 60 Seconds as required. A loose connection on the Digital Reference Unit Load was found.	The DRUL Circuit does not affect Isochronous Operation, therefore, the DG would have Functioned during a LOOP or LOCA with LOOP	Loose wiring tightened.	
12704	S	1	0	0	3/13/2000	S	1	0	0	Control	DG Failed to respond to Raise/Lower voltage demand from Volt Reg Norm/Stby Sel Switch. This caused to Voltage Regulator to fail as-is.	The Normal Voltage Controller was unavailable and it is unknown how this would affect Isochronous Operation	Control Switch Replaced	Assumed that the DG would not have been able to power bus
12705	L	0	1	0	5/26/2000	L	0	1	0	Control	EDG Tripped after reaching rated speed and voltage due to a failed Circuit Board that falsely input a fuel rack differential trip.	DG Tripped less than 1 hour of loaded run. EDG was unavailable to provide emergency power	Circuit Board was replaced	
12707	S	1	0	0	10/29/2000	S	1	0	0	Control	EDG Conditioner Display failed while Engine in Standby. Discovered condition through normal plant rounds	DG was inoperable and would not function to provide power	Conditioner repaired	
12918	R	0	0	1	11/15/2000	None	0	0	0	Coolant	DG Engine Driven Jacket Water Pump Seal leak discovered during manual engine barring. Leak was minor, however engine was declared inoperable	DG would have been able to start, load, and run for several hours	Seal was replaced	Since engine would have run loaded for greater than 1 hour, run failure mode has been assumed.
13186	None	0	0	0	6/17/1999	None	0	0	0	Operator Error	Incorrect Test Equipment connected to 2C DG while engine was being tested. Test Equipment had an output that caused unexpected starting of Room Exhaust Fan	None. When maintenance and testing was complete, Engine was restored to service	Proper Test equipment procured	
13327	None	0	0	0	3/10/2001	None	0	0	0	Sequencer	E3 DG had an electrical Jumper left control circuits that caused the B ESW Pump to start inadvertently. The jumper was supposed to have been removed in a subsequent procedure step. Engine was not in operation	None. The EG was in test at the time. The failure was similar to a Sequencer Issue.	Test Jumper removed from circuit.	Similar to a Sequencer Issue
13720	None	0	0	0	1/21/2000	None	0	0	0	Sequencer	SEC Testing resulted in a Failed Automatic Test Insertion module. This is similar to a Sequencer Failure	DG may not have started with failure present. This is similar to a Sequencer Malfunction where the DG is unaffected	A malfunctioning relay was replaced	Similar to a Sequencer Issue
13786	None	0	0	0	2/27/1999	None	0	0	0	Generator	EDG voltage went to 2kV after starting, then hesitated prior to reaching 4kV as required. Time to reach 4kV exceeded required 10 seconds. The problem was in the Field Flash Circuitry.	EDG was unavailable for power production	Trouble shooting and repair was performed on the Voltage Regulator.	Recommended by NEI review to be removed as a failure.
13807	L	0	1	0	9/10/1999	S	1	0	0	Breaker	52HG10 4kV Brkr to MCC 1G, 125 VDC control switch and red light lamp socket, found broken during operator round.	Would prevent EDG Breaker from closing on Bus. Also, if a seismic event had shorted out the lamp socket, it could have caused a loss of power to MCC 1G.	Replaced Lamp Socket, Control Switch, and Fuse	

1999 - 2001 EDG Failures

Failure ID	Recommended EDG Failure Mode	Start	Load	Run	Discovery Date	Industry Code	Start	Load	Run	Category	Failure Description	Impact	Corrective Action	Comment
13811	None	0	0	0	2/28/2000	None	0	0	0	Not Applicable	DEG3 failed to start when demanded during Test. A jumper installed in accordance with procedure should have supplied voltage to the DEG staring relay, however, there was no voltage present at the designated points. The points were on the Auto/Manual Selector Switch. It was later determined that the switch was configured correctly, however the Test was incorrect.	None. The Start Procedure was incorrect. The EDG would have performed as designed after the test when restored	The Test was corrected to reflect configuration	
13904	R	0	0	1	10/12/1999	S	1	0	0	Breaker	DG Output Breaker opened on Overcurrent during Loaded Test Run. Breaker opened 22 hours into 24 hour test run due to voltage regulator transformer becoming Grounded.	DG 2-1 failed Loaded Run Test	Transformer Replaced	
13919	None	0	0	0	6/17/1999	None	0	0	0	Not Applicable	Control Room Appendix R Lighting Battery failed test	None. This is not a DG malfunction	Power Supply was replaced with a functioning one	This is not related to DG Equipment
14089	L	0	1	0	12/31/1998	L	0	1	0	Control	EDG Tripped on Overcurrent during routine Testing, from a loaded run. The Voltage Regulator was malfunctioning.	EDG tripped in less than one hour and was not available.	Voltage Regulator was repaired	
14095	None	0	0	0	1/13/1999	None	0	0	0	AAC	App R DG 15 AMP Feeder Breaker to EDG Auxiliaries Tripped open. Trouble Alarm annunciated this condition to the Control Room.	App R DG waas not available during the time the breaker was tripped	Breaker reset	
14110	None	0	0	0	8/25/1999	None	0	0	0	Fuel (Other than transfer)	EDG Monthly Fuel Oil Sample showed that the Storage Tank had 5 inches of water and there was evidence of Microbiological Growth.	None. EDG and Day Tank was unaffected	Tank cleaning and coated	
14116	S	1	0	0	5/19/1999	S	1	0	0	Lube Oil	EDG had a Lube Oil Leak at the Heat Exchanger Gasket	EDG was unavailable to run until leak was repaired	Leak Repaired	
14118	None	0	0	0	5/12/1999	None	0	0	0	AAC	App R DG Upper Air Start Motor Failed. Engine started however due to the Lower Air Start Motor functioning.	None. Engine started successfully on one Air Start Motor	Bendix Drive repaired	This is an Appendix R Engine
14120	None	0	0	0	6/13/1999	None	0	0	0	AAC	App R DG Tripped from Full Load due to High Jacket Water Temperature during test. Radiator Cooling Fan Motor failed	App R DG was not available until Fan Motor replaced. Engine ran for under 1 hour loaded	Replaced Fan Motor for Radiator	This is an Appendix R Engine
14121	None	0	0	0	6/17/1999	None	0	0	0	AAC	App R DG Lube Oil Heaters were found de-energized due to a loose wire.	App R DG was not affected	Repaired Heater	This is an Appendix R Engine
14125	None	0	0	0	9/15/1999	None	0	0	0	Control	33 EDG "Start Defeated" Alarm Annunciated due to a failed relay.	DG function was not lost	Replaced Relay	Engine remained in Auto
14156	S	1	0	0	4/18/2000	None	0	0	0	Engine	EDG Test Run was cut short due to a large Oil Leak at Cylinder 7R. The Engine was emergency shutdown.	DG Function was lost until it was repaired	Leak Repaired	
14169	S	1	0	0	8/6/2000	None	0	0	0	Lube Oil	EDG Pre-Lube Pump was found in the OFF position and Lube Oil and Jacket Water Temps were Low out of Specification. This was due to a blown fuse in the Feeder Breaker	EDG may have started however it is not certain	Fuse replaced	
14540	S	1	0	0	2/23/2001	S	1	0	0	Control	EDG could not be raised to full speed. Mechanical Governor needed adjustment.	Engine did not reach full speed and was not able to be loaded	Mechanical Governor required adjustment	
14756	L	0	1	0	3/6/2000	S	1	0	0	Coolant	DG Intercooler Temperatures rose out of specification due to TCV Disk Separated from Valve Stem.	Engine had to be shutdown	Repaired TCV	

1999 - 2001 EDG Failures

Failure ID	Recommended EDG Failure Mode	Start	Load	Run	Discovery Date	Industry Code	Start	Load	Run	Category	Failure Description	Impact	Corrective Action	Comment
15174	None	0	0	0	3/17/1999	None	0	0	0	Coolant	Service Water Leak on elbow on Heat Exchanger Tube Side Vent Elbow. Pipe was found corroded.	DG was unavailable for operation	Minor through-wall leak. Repaired Leak	Recommended by NEI review to be removed as a failure.
15175	None	0	0	0	3/29/1999	None	0	0	0	Sequencer	Part of D/G test to cycle UAT Breaker Failed. Breaker did not open as demanded due to loose Posts on back of K85 Relay.	None. DG functioned as required. This was not the DG Output Breaker	Repaired Relay.	This is similar to a Sequencer Issue
15179	None	0	0	0	3/30/1999	None	0	0	0	Sequencer	EDG Output Breaker did not Close during Surveillance Testing because UAT Brkr to the Emergency Bus Failed to Open as required to satisfy EDG Brkr Logic. UAT Relay K85 Failed to function as required.	None. DG functioned as required. This was not the DG Output Breaker. This would have resulted in a emergency EDG failure to load.	Repaired Relay.	This is similar to a Sequencer Issue
15199	None	0	0	0	10/8/1999	None	0	0	0	Air Start	Air Start line Check Valves are weeping air past its seat	None. Leakage was slight	Replaced checkvalves	Engine did not fail to start
15209	None	0	0	0	4/30/1999	None	0	0	0	Air Start	DG-V72A Compressor Discharge Relief Valve leaks continuously.	None. This failure affected AC 2A only. The air start system has multiple air compressors	Replaced RV	Air Start system was in standby when this condition was discovered
15227	S	1	0	0	11/1/2000	S	1	0	0	Engine	DG had to be shutdown due to High Crank Case Exhaust Pressure and Vibrations. In addition, smoke was reported in DG-1B building.	EDG was not loaded at the time of the trip	Engine had to be extensively rebuilt.	Engine was not available for start.
15228	None	0	0	0	12/1/2000	S	1	0	0	Engine	DG was recently rebuilt due to extensive damage. During its break-in runs engine had to be shutdown due to high d/p across lube oil strainer indicative of bearing failure.Bearing failure heating caused damage to multiple other components.	Engine was loaded for less than 1 hour when the damage occurred. Engine required complete rebuild.	Engine Rebuild.	Recommended by NEI review to be removed as a failure. Engine was not available for run but appears to be related to a maintenance activity and was identified during a post maintenance test.
15441	L	0	1	0	6/8/1999	S	1	0	0	Breaker	DG Output Breaker to 14 Bus Failed to Close. Breaker Trip Bar Misalignment prevented breaker operations. Breaker Frame had loose screws in C Phase Arc Chute	Breaker Failure prevented DG from loading bus. This is a Load Failure because the breaker was demanded to close but did not close.	Breaker Rebuild	
15633	S	1	0	0	1/10/2001	L	0	1	0	Control	EDG failed to Develop Voltage after coming to rated speed during testing. Two shorted Diodes in the Rectifier Bridge	Although the engine started, the generator was unavailable to provide electrical power.	Rectifier Diodes were replaced	Failed to develop voltage therefore this is a Start Failure. The breaker never closed in on the Bus
15634	S	1	0	0	12/21/2000	S	1	0	0	Control	Unstable Governor output caused DG to hunt and swing during unloading from load. Additionally, the DG experienced oscillations in load and speed during loaded operation and during unloaded operation	EDG was not available for loaded operation greater than one hour nor was it stable during unloaded operation therefore this is a failure to start	Governor modified	There were several run attempts that caused the DG load to oscillate prior to one our of loaded run.
15635	S	1	0	0	12/21/2000	S	1	0	0	Control	Unstable Governor output caused DG to hunt and swing during unloaded, loading, and unloading operations. The cause was determined to be multifold including soldered joint connections and HVAC air flow interaction.	EDG was not reliably available to start.	Governor and HVAC system modified.	
15636	S	1	0	0	12/21/2000	S	1	0	0	Generator	EDG tripped on overspeed due to failed exciter diodes. The failed diodes prevented voltage from developing after field flash was applied.	EDG was not available to start.	Diodes were replaced.	
15973	S	1	0	0	1/12/1999	S	1	0	0	Control	EDG Feeder Breaker Current Transformer (CT) epoxy insulation liquified due to a known process.	EDG was taken out of service until CT was replaced	Replaced CT with a liquification resistant epoxy	EDG was assumed to be inoperable until CT repair was completed
15988	None	0	0	0	9/9/1999	R	0	0	1	Generator	Div 3 DG was emergency shutdown after sparks and smoke came from Generator during 24 hour endurance run.	Div 3 EDG was unavailable for loaded run.	Cause of Generator failure repaired	HPCS Diesel Generator - screened
16038	S	1	0	0	2/19/2001	S	1	0	0	Engine	Div I EDG Turbocharger Cooling Water Crack leaking and worsening as 24 hour run commenced.	Assumed that EDG was not loaded when failure necessitated engine shutdown	Leak Repaired	
16039	S	1	0	0	2/21/2001	S	1	0	0	Fuel (Other than transfer)	Div 1 EDG Fuel Injector Plug developed a Fuel Leak. The leak was caused by an Injector Plug that became loosened.	EDG was immediately shutdown and taken out of service.	Leak Repaired	

1999 - 2001 EDG Failures

Failure ID	Recommended EDG Failure Mode	Start	Load	Run	Discovery Date	Industry Code	Start	Load	Run	Category	Failure Description	Impact	Corrective Action	Comment
16048	S	1	0	0	5/17/2001	S	1	0	0	Coolant	Div 2 EDG Jacket Water Level was intentionally lowered. Later, the Low Jacket Water Tank Level Alarm annunciated. A crack was found in the Drain Valve Yoke Nut which caused the valve to leak through.	EDG was declared inoperable and removed from Standby. This failure would have prevented EDG from Starting.	Leak Repaired	
16141	S	1	0	0	1/10/1999	S	1	0	0	Operator Error	EDG Control Power was inadvertently tagged out.	EDG was unavailable to start and run manually or automatically.	AC control power was restored	
16168	None	0	0	0	10/27/1999	S	1	0	0	Air Start	Air Start Motor failed to start EDG, which automatically shutdown during a start attempt, on Start Failure Lockout.	Although the Opposite Side Air Start Motor subsequently started the EDG, this engine was declared out of service. EDG was unavailable for starting	Air Start Motor was replaced	Recommended by NEI review to be removed as the failure was assoicated with one of two start headers. The second air start was available but isolated for the test.
16235	None	0	0	0	4/12/2001	S	1	0	0	Air Start	Rust scale blocking Air Start Pressure Control Valves in the Air Start System caused a failed start attempt on the EDG.	EDG was unavailable to start and run manually or automatically.	Strainers were installed in the system and procedures to clean them were adopted	Recommended by NEI review to be removed as the failure appears to be assoicated with one of two start headers.
16238	None	0	0	0	6/2/2001	None	0	0	0	Ventilation	EDG 1 Supply Fan Inlet Damper failed in the Closed Position resulting in the EDG being declared Inoperable	EDG 2 was unavailable to start and run manually or automatically.	Replaced damper hydramotor	EDG room Supply fans were used to lower Room Temperature without EDG in operation. It is doubtful that the EDG would have been able to Load without the Damper in operation. Ventilation system is OOS based on MSPI scoping document.
16435	None	0	0	0	9/18/1999	None	0	0	0	Sequencer	Sequencer Failed Test	EDG was not available to start.	Replaced Optical Isolater on Sequencer.	This is a Sequencer issue
16689	S	1	0	0	8/18/2000	S	1	0	0	Control	EDG Tripped on Voltage Spike. Ground Relay Tripped due to a poor connection of the Potential Transformer primary side through a loose knife switch.	EDG was not available to start.	Replaced and tightened PT Stabs and Knife Switch connections	EDG did not achieve rated speed and voltage prior to engine trip
16691	S	1	0	0	10/13/2000	S	1	0	0	Control	DG tripped due to a voltage spike when the K1 Relay contacts failed. DG A Normal Voltage Regulator swapped to Standby Voltage Regulator while engine was being started.	EDG was not available to start. EDG was being tested subsequent to maintenance to replace the SCRs	Replaced K1 Contactors	
16815	S	1	0	0	9/25/1999	S	1	0	0	Air Start	EDG declared inoperable based on Air Starting System Pressure <165psi. The Right Bank Air Dryer Relief Valve was relieving continuously bringing the air pressure to 150 psig. The Left Bank Compressor was inoperable for a motor replacement.	EDG was not available to start.	The Right Bank Air Dryer was manually by-passed and isolated. This restored starting air pressure but did not cause the EDG from being declared Operable.	This Starting Air System failure rendered the EDG unable to start.
16817	S	1	0	0	11/7/1999	S	1	0	0	Control	EDG Control Power Ground occurred on the +48 VDC Bus preventing it to achieve 900 RPM during fast speed start. EDG was shutdown immediately thereafter. Troubleshooting found that the Field Flash Relay and Field Flash Cutout Relay needed replacement.	EDG failed to start within normal parameters.	The Field Flash and Cutout Relays were replaced.	
16821	S	1	0	0	3/10/2000	S	1	0	0	Control	EDG Governor failed to bring speed up to rated Frequency during testing and prior to loading. After loading with the low frequency, the normal Bus Feeder Breaker Tripped. The breaker tripped prior to 1 hour of loaded operation.	The licensee decided to continue the test with the low frequency condition. After they loaded the engine the normal bus feeder breaker tripped due to EDG load swings. This condition is a Failure to Start because the rated Frequency was not satisfactorilly achieved.	Governor was repaired.	INL evaluated this as a Run Failure. This is a Start Failure because although the licensee Loaded the EDG with the faulted Governor, causing a subsequent transient, the EDG did not meet start criteria.
16836	None	0	0	0	1/28/2001	None	0	0	0	Control	3B EDG Governor Failed to control Speed due to a loose Lock Nut which had vibrated off of speed adjuster. This caused the mechanical governor to lock up near the upper limit.	The Speed controller failure does not affect the EDG's ability to load the bus from a LOOP. Therefore, this failure is not a Start Failure.	Lock Nut on Governor Speed Motor repaired	This Failure did not affect the EDG's ability to start and load the Bus from a LOOP, however, it would preclude the ability to Parallel with Offsite Power when it is restored. This would necessitate the need for a Dead Bus restoration post LOOP

1999 - 2001 EDG Failures

Failure ID	Recommended EDG Failure Mode	Start	Load	Run	Discovery Date	Industry Code	Start	Load	Run	Category	Failure Description	Impact	Corrective Action	Comment
17391	S	1	0	0	3/1/1999	S	1	0	0	Control	DG failed to maintain Frequency during the 18 Month Surveillance due to a bad Governor Resistor.	DG failed to load	All DG Governors at Watts Bar have been replaced to those that do not require this component.	One sentence description. The frequency swings implies that the EDG is not paralled
17428	None	0	0	0	9/8/1999	None	0	0	0	Ventilation	EDG Annunciators for "Crankcase Pressure HI" and DG Auto Start Locked Out" came in, in response to work being performed on the Room Ventilation Dampers. When an HVAC Damper failed shut, it caused a vacuum in the room, which actuated the Crankcase Pressure Switch Trip	The EDG was in Standby at the time of the lockout. The lockout prevented the EDG from starting if a demand signal came in. Therefore, the EDG would not have been able to start, load, and run if demanded.	HVAC equipment was repaired	This issue is related to room ventilation, the engine would not be able to perform its mission to to the vacuum in room.
17488	None	0	0	0	6/28/2000	None	0	0	0	Ventilation	EDG Failed performance test because Room HVAC Exhaust Fans found inoperable. The HVAC fans were not properly reset at the conclusion of a Fire Detector Test as required.	EDG is assumed to have started, but was not able to be loaded and run	HVAC Relay was reset.	Room ventilation issue.
17508	L	0	1	0	5/16/2001	S	1	0	0	Breaker	EDG Spring Charging Motor was installed incorrectly which caused the breaker to remain Closed when its Hand Switch was taken to Trip Position, during a test. A new style Spring Charging Motor should have had a spacer installed, about which no vendor instructions were provided.	EDG would not have been available to load if a demand signal was present. This condition is considered a Start Failure because the Breaker would malfunction.	Installed Breaker Spring Charging Motors correctly	This is a Load Failure because it is not assured that the Breaker would close in on the Bus
17612	None	0	0	0	10/20/1999	S	1	0	0	Control	Approximately 18 hours while at Full Load, EDG B Load output increased with no operator action. Further, the Load failed to be controlled with operator intervention due to a Governor Malfunction. The governor malfunction was only in the Speed Droop Side and not with the Isochronous portion of the governor	Trouble shooting efforts showed that If the EDG was running in Isochronous mode, there would have been no output swings. Therefore, there is no failure with this engine	Governor Speed Droop was adjusted so that when the EDG is paralleled to the grid, the governor would be more responsive to voltage swings on the grid	
17670	None	0	0	0	8/9/2000	None	0	0	0	Not Applicable	A Fire Door was found to be inoperable between two ESF Switchgear Rooms	None of EDG operations	Locksmith fixed door latch	This event is not EDG related
17671	S	1	0	0	8/29/2000	S	1	0	0	Control	EDG tripped on Volts/Hertz at the time the Generator was being Unloaded and the Breaker opened. This caused a Breaker Lockout. The 5B Relay was found to be defective. This relay malfunction would have prevented future EDG Starts	The EDG would have not been available to Start	5B Relay was replaced	This event would prevent DG subsequent starts. This relay failure would not have prevented the EDG from continuing to run.
17678	L	0	1	0	12/20/2000	L	0	1	0	Control	EDG Tripped during manual loading. When the EDG was synchronized, it immediately accepted 4MW and tripped when the operator attempted to reduce load. The UPR in the Governor was determined to have high resistance in the contacts	This is a Load Failure because the EDG was loaded when it tripped.	The Governor was subsequently modified	
17706	None	0	0	0	1/17/2001	S	1	0	0	Control	EDG did not reach rated speed or voltage during Maintenance Run Start. The engine tripped on Volts/Hertz due to an out of adjusted Motor Operated Potentiometer.	EDG was out of service for maintenance	Adjusted MOP Settings	Not considered to be a failure as it is assumed that the potentiometer was out of adjusted due to maintenance.
18032	None	0	0	0	2/19/2000	None	0	0	0	Not Applicable	Spillway DG failed batter caused engine start failure	Spillway DG is not Safey Related Engine	Replaced Battery	Not a safety related EDG
18067	S	1	0	0	4/4/2000	S	1	0	0	Engine	EDG failed to Start on LOOP to its associated bus. A piston was found hydraulically locked and filled with oil.	EDG Failed to start on valid demand signal	None specified	
18072	None	0	0	0	7/11/2000	None	0	0	0	Not Applicable	4C HVAC Chiller Outlet Isolation valve failed to open on signal.	Chiller was out of service	Replaced Solenoid	Not a EDG Failure
18074	None	0	0	0	6/22/2000	None	0	0	0	Not Applicable	EDG Trouble Alarm annunciated because Brkr 1-EE-BKR-1J1-1-G2 had tripped and MCC 1J1-A became De-Energized. The cause of the De-Energized MCC was that a Load, 1-HV-F-22C Motor in the HVAC System, failed and drew large amount of current. A breaker problem caused the entire MCC that feeds power to the 1J EDG to become De-Energized.	This condition would have prevented the DG from starting and loading.	Replaced the HVAC Motor	Protective tripping failed to prevent the lost of MCC which resulted in failure of the EDG. NEI review recommended removal of this failure as the failed component is outside the EDG boundary.

1999 - 2001 EDG Failures

Failure ID	Recommended EDG Failure Mode	Start	Load	Run	Discovery Date	Industry Code	Start	Load	Run	Category	Failure Description	Impact	Corrective Action	Comment
18075	None	0	0	0	6/22/2000	S	1	0	0	Control	EDG 1J Trouble Alarm annunciated because Brkr 1-EE-BKR-1J1-1-G2 had tripped and MCC 1J1-A became De-Energized. The cause of the De-Energized MCC was that a Load, 1-HV-F-22C Motor in the HVAC System, failed and drew large amount of current. A breaker problem caused the entire MCC that feeds power to the 1J EDG to become De-Energized.	This condition would have prevented the DG from starting and loading.	Replaced the HVAC Motor	Appears to be a duplicate of 18075.
18118	None	0	0	0	1/10/2001	None	0	0	0	Not Applicable	Axial Tilt Rod Deviation Alarm annunciated due to a drifting IRPI. This condition was caused by a failed SOLA transformer	This is not a Diesel Generator Malfunction	Replaced SOLA Transformer	
18132	None	0	0	0	4/19/2001	None	0	0	0	Not Applicable	Battery Cell found reading low.	Voltage was out of specification low for this Cell, however this condition did not cause an EDG failure	Replaced Cell	
18134	None	0	0	0	5/12/2001	None	0	0	0	Not Applicable	2B Screen Wash Pump circuit breaker Control Transformer had a short circuit. Circuit Breaker Failed.	This is not a Diesel Generator Malfunction	Replaced Breaker and transformer	
18285	None	0	0	0	6/3/1999	None	0	0	0	Not Applicable	Battery Cells found reading low.	Resistance was out of specification high for several Cells, however this condition did not cause an EDG failure	Replaced Cells	
18292	None	0	0	0	9/3/1999	None	0	0	0	Ventilation	2-HV-F-40B Room Fan was found running with its discharge Damper closed. Damper Failure of the Auxiliary contactor within the 480v power supply	This failure did not affected EDG operation	Replaced contactor	This failure is assumed to not affect EDG operability, it is not an EDG Room Ventilation Fan
18321	None	0	0	0	1/16/2000	None	0	0	0	Not Applicable	4A HVAC Chiller Outlet Isolation valve failed to open on signal.	Chiller was out of service	Replaced Thermal Overload	Not a EDG Failure
18395	None	0	0	0	5/27/2001	None	0	0	0	Ventilation	Breaker for 2-HV-F-40B Room Fan was found Tripped an hour after starting a Test. A and B Phase wiring was found loose	This failure did not affected EDG operation	Rewired Breaker	This failure is assumed to not affect EDG operability, it is not an EDG Room Ventilation Fan
18665	None	0	0	0	4/9/1999	None	0	0	0	AAC	SBO Engine "Low Starting Pressure" alarm annunciated with both air compressors running. Air was coming out of the Air Dryer Drain Traps which were not isolable.	SBO Engine was not available to start	New drain traps were installed	This is a SBO engine
18688	None	0	0	0	7/18/1999	S	1	0	0	Air Start	"#3 EDG Trouble" Alarm annunciated due to low air pressure alarm. Air Compressor 3-EG-C-1 would not start even though the air pressure at the Pressure Switch was below 165 psig. At the time, the Air Bottle Pressure was greater at 165 psig, just above the limit required for ensuring a EDG start. The Pressure Switch was found to be defective.	Although EDG would have been unavailable to start if the Starting Air Header Pressure was slightly under 165 psig, the Engine was administratively declared inoperable.	Air Pressure Switch was replaced	Conservativley, this event has been evaluated as not a failure, even though the EDG was declared Inoperable.
18696	None	0	0	0	7/21/1999	None	0	0	0	Air Start	#1 Compressor for all EDGs experienced Motor Contactor Chatter each time the compressor shuts off, due to faulty control circuitry. In one instance the associated compressor breaker, tripped on TOL.	EDG 3 was not declared inoperable because system air pressure was high enough to permit required EDG starts.	Contactors replaced and logic modified	The event was is evaluated as no failure because the Air Start System Pressure was adequate to start the EDG
18697	None	0	0	0	7/30/1999	S	1	0	0	Air Start	#2 Air Compressor Failed to start during its Test. Pressure tap location was unsuitable for use with recently changed pressure switches.	EDG 1 was not declared inoperable because system air pressure was high enough to permit required EDG starts.	Location of the Pressure Taps will be modified so that they would work with the new style pressure switches.	
18699	None	0	0	0	8/9/1999	S	1	0	0	Air Start	#1 Air Compressor for EDG 3, would not start. The TOL at the MCC was actuated because the Pressure Switch sensitivity was too high for the Air Compressor Impulses. This caused the TOL to trip the Air Compressor Breaker	EDG 3 was not declared inoperable because system air pressure was high enough to permit required EDG starts.	Location of the Pressure Taps will be modified so that they would work with the new style pressure switches.	
18716	None	0	0	0	12/6/1999	None	0	0	0	AAC	SBO DG Failed maintenance test due to over loading. A factory defect was responsible for the failure	SBO DG was unavailable	Cause of problem was corrected	SBO Diesel

1999 - 2001 EDG Failures

Failure ID	Recommended EDG Failure Mode	Start	Load	Run	Discovery Date	Industry Code	Start	Load	Run	Category	Failure Description	Impact	Corrective Action	Comment
18730	None	0	0	0	4/15/2000	None	0	0	0	Control	A Failed resistor caused the EDG Battery Charger output to go to 147 VDC and 28 Amps, which is greater than specifications.	For this event it is assumed that the Battery Charger is necessary for the long term operation of the EDG. The event does not describe the function of the Battery therefore it is conservatively assumed that it is used for Control Power. The EDG would start as required with the battery charger failure, however, it would not continue to Run as the battery charger is unavailable.	Resistor in the Battery Charger was replaced	
18750	S	1	0	0	8/22/2000	S	1	0	0	Control	EDG found running with Mechanical Overspeed Lever in the Actuated Position during Surveillance Test. Breaker was also found tripped open.	EDG would not have been able to start and carry load if required.	Overspeed Trip assembly was repaired	
18788	None	0	0	0	2/2/2001	None	0	0	0	AAC	Valve on Discharge of "B" Compressor for the SBO DG Air Start System came apart during operation and damaged compressor.	None because the SBO DG Air Start System was still capable of starting DG	Comperessor rebuilt	SBO Diesel
18799	None	0	0	0	5/22/2001	None	0	0	0	AAC	SBO DG Air Compressor #1 Breaker was found tripped open. "C" Phase Termination found loose.	None because the SBO DG Air Start System was still capable of starting DG	Breaker Rewired	SBO Diesel
19195	S	1	0	0	7/24/1999	S	1	0	0	Air Start	EDG Air Start System Flexible Hose Split, causing Air Receivers to lose pressure. "Starting Air Pressure Low" Alarm annunciated.	EDG was unavailable to start.	Hoses were replaced	Air Receivers lost air pressure during this event.
19198	S	1	0	0	11/11/1999	S	1	0	0	Breaker	EDG Output Breaker failed to Open at conclusion of Surveillance Test. Breaker had to be opened Locally. Problems occurred in Switch Wiring.	This event is conservatively evaluated as a Start Failure because it is not apparent whether the Breaker Wiring Problem would have allowed Breaker to Close as required.	Switch Rewired	Unclear as to whether this breaker would close in future demands. Assumed to be a failure to start.
19314	S	1	0	0	3/16/1999	S	1	0	0	Generator	EDG failed to Flash the Generator field during Surveillance Test Auto-Start. Control Power fuses were found to be blown.	EDG experienced a Start Failure because it could not provide power to its associated bus.	Fuses Replaced	
19363	None	0	0	0	6/16/1999	None	0	0	0	Sequencer	Bistable discovered with voltage high out of specification prior to failing. Bistable condition was found during PM activities on that Sequencer.	This is a Sequencer problem where it would prevent the sequenced loading of equipment after D/G Breaker Closure	Sequencer Power Supplies replaced	Sequencer Issue
19364	None	0	0	0	6/16/1999	None	0	0	0	Sequencer	Sequencer DC and AC power supplies degraded such that AC ripple was bleeding through the DC side. Condition was found during PM activities on the Sequencer	This is a Sequencer problem where it would prevent the sequenced loading of equipment after D/G Breaker Closure	Sequencer Power Supplies replaced	Sequencer Issue
19386	R	0	0	1	2/11/2000	None	0	0	0	Coolant	EDG Jacket Water Pump Mechanical Seal was discovered to be degraded and leaking during Preventive Maintenance Activities. Subsequent analysis determined that the Engine would not be able meet its 7 day Run requirement.	Engine would have not met its 7 day Run Time, therefore this is a Run Failure	Seal was replaced	Licensee determined that the Leakage would have exceeded the makeup capacity of the Jacket Water Head Tank
19387	S	1	0	0	6/7/2000	S	1	0	0	Lube Oil	Diesel Lube Oil Keep Warm Pump tripped during standby operation. It was found to have a Failed Outboard Bearing during Troubleshooting Activities, due to improper grease. A Bearing Sleeve was found to block the grease path to the bearing internals.	This event is conservatively evaluated as a Start Failure because it is not apparent whether the loss of Lube Oil Prelube would have prevented the engine to start successfully.	Bearing was re-fit with a proper Rotor Sleeve that would allow grease passage to the bearing internals.	Fairbanks Morse engines typically use Lube Oil Pressure to avoid a start failure. The engine also requires initial oil pressure to protect the most remote bearings from damage during start.
19505	S	1	0	0	8/11/2000	S	1	0	0	Engine	EDG had excessive Wrist Pin Bearing Wear as found by vendor recommended routine Lube Oil Analysis.	This event is conservatively evaluated as a Start Failure because bad wrist pin bearings could have affected engine starting.	Engine was rebuilt.	
19815	S	1	0	0	6/1/2001	S	1	0	0	Control	EDG failed to start during testing due to failed UV initiation Relay. Relay and its contacts were in a degraded condition.	This event is a Start Failure	Relays were replaced	
19816	None	0	0	0	6/20/2001	S	1	0	0	Air Start	DG 2 Air Start System pressure boundary found degraded but not leaking. Air Start System degradation was identified through UT examination.	None because the EDG Air Start System was still capable of starting DG	Corroded fittings were replaced	
19918	None	0	0	0	1/21/1999	None	0	0	0	AAC	TSC DG Starting Motor Battery did not function to start TSC DG during Test	TSC Diesel would not have been available	Batteries replaced	TSC Engine

1999 - 2001 EDG Failures

Failure ID	Recommended EDG Failure Mode	Start	Load	Run	Discovery Date	Industry Code	Start	Load	Run	Category	Failure Description	Impact	Corrective Action	Comment
19940	None	0	0	0	2/22/1999	None	0	0	0	AAC	TSC DG Radiator leaking while engine was running for test. Engine ran for 1.5 hours before failure occurred. Piece of metal from roof damaged some radiator tubes.	TSC Diesel would not have been available to Run	Tubes repaired	TSC Engine
20019	L	0	1	0	3/15/2001	S	1	0	0	Breaker	DG was being shutdown from a Surveillance run. DG output breaker was taken to Open, however, "Bus 6 from D/G B breaker 1-603 Closed" alarm was annunciating. This alarm should have cleared when the breaker was open. It was found that Breaker linkage was disconnected such that the breaker was no longer operable.	This event was conservatively evaluated as a Start Failure because the disconnected linkage could have prevented closure of the breaker.	Breaker Linkage Cotter Pins needed to be replaced and bent correctly.	
20027	None	0	0	0	7/25/2001	S	1	0	0	Breaker	Breaker for KHU-1 was modified incorrectly such that it would not operate as required to bring power from the Hydro Unit to the Emergency Buses. An Inertia paddle was replaced on the Breaker and its function was restored.	The Hydro Unit was not available and is considered a Start Failure	The Breaker was repaired	This is a Hydroelectric Dam
20031	L	0	1	0	4/10/2001	L	0	1	0	Control	During Test, EDG failed to develop Voltage, however, its Output Breaker Closed as expected. This caused a LOOP on the associated bus, which caused the EDG to run without Cooling Water for 10 minutes prior to shutting down the EDG. The K1 Relay failed to Open to allow the Generator to build up voltage.	As the EDG failed to develop the propoer voltage, it is assumed to be a start failure.	The K1 Relay was repaired. The EDG was checked for damage.	
20062	None	0	0	0	7/25/2001	S	1	0	0	Control	23 EDG Failed to Start during a Post Maintenance Test. A new Governor Servo Motor was not vented properly.	Servo Motor issued result EDG failure to reach rated RPM and voltage. Servo failure rated to maintenance being performed - Screened.	Governor Booster was replaced	
20127	L	0	1	0	10/29/2000	S	1	0	0	Control	EDG Voltage and VARS were unable to be controlled upon connecting the generator to its associated Bus. Failure attributed to malfunctioning Auto Voltage Regulator Circuit Board.	This is a Load Failure because the EDG was loaded when it was shutdown	Auto Voltage Circuit Board was replaced	
20143	None	0	0	0	8/29/2001	None	0	0	0	Not Applicable	Keowee U2 Field Breaker would not close when demanded	Keowee was unavailable	Repaired Breaker	This is a Hydroelectric Dam
20225	L	0	1	0	8/7/2001	S	1	0	0	Breaker	DG Breaker to Bus 17 failed to Close during Test due to excess play in Breaker Mechanism.	This is a Start Failure	Repaired Breaker	
20235	None	0	0	0	4/6/2001	None	0	0	0	AAC	13.8 kV related Alarms annunciated in the Control Room beacause Feeder 13W93 was deenergized.	Offsite Power Sources needed to be verified from different Line	Restored Feeder	This is a Gas Turbine
20236	None	0	0	0	7/10/2001	S	1	0	0	Fuel Transfer	EDG 1B Fuel Oil Day Tank "Hi" and "Hi Hi" Alarms annunciated with Fuel Oil Transfer Pump running. Before the FOTP was manually secured, the Day Tank overflowed approximately 80-100 Gals. The Level Control Switch malfunctioned. EDG 1B was in Standby at the time and was unaffected	Oil Leaked into the Room Sump Trench which is designed to handle Day Tank Overflows. The EDG was unaffected.	Level Switch was calibrated.	Engine could have started and performed its function in presence of fuel in the trench
20244	None	0	0	0	7/25/2001	S	1	0	0	Fuel Transfer	Fuel Oil Transfer Pump failed to automatically stop when the Day Tank Level switch, Hi Level Limit was reached. Operator manually shut pump down before tank overflowed.	EDG 1B was unaffected. The Day Tank had adequate level to support EDG Operations in the short term. The Fuel Oil Day Tank was able to be filled if required.	Level Switch was calibrated.	
20257	None	0	0	0	4/10/2001	None	0	0	0	Not Applicable	System Operator performed Switching Station Breaker Manipulations that rendered one of the Required Offsite Sources Inoperable to Cooper, without warning Plant Personnel.	LCO 3.8.1.A for one offsite circuit inoperable Entered.	System Operator restored Line to operability.	This event is not EDG related
20392	L	0	1	0	8/8/2001	S	1	0	0	Control	EDG failed to respond to Voltage Regulator Manual Control during Loaded Operation. VAR loading dropped without adjustment and would not respond to Control Board signal adjustment.	This event is a Load Failure because the Voltage Regulator failed while paralelled.	Unknown	This event was assumed to have occurred prior to one hour of loaded operation

1999 - 2001 EDG Failures

Failure ID	Recommended EDG Failure Mode	Start	Load	Run	Discovery Date	Industry Code	Start	Load	Run	Category	Failure Description	Impact	Corrective Action	Comment
20393	L	0	1	0	8/13/2001	S	1	0	0	Control	EDG failed to respond to Voltage Regulator Manual Control during Loaded Operation. VAR loading dropped without adjustment and would not respond to Control Board signal adjustment.	This event is a Load Failure because the Voltage Regulator failed while paralelled.	Unknown	This event was assumed to have occurred prior to one hour of loaded operation
20404	S	1	0	0	8/8/2001	S	1	0	0	Control	EDG experienced spurious annunciation for Oil Pressure, Low Water Pressure, and Overspeed after generator after successful completion of test. A faulted LWD Relay was most likely the cause.	A relay failed. It is assumed that the annunciation is tied with actuation of the trips, therefore EDG unavailable when the faulted relay occurred. The EDG would have been unavailable for Starting after this event.	Relays were replaced	This is assumed to be a failure during Unloading.
20440	S	1	0	0	5/9/2001	S	1	0	0	Control	EDG failed to develop Voltage due to malfunction in the K1 Relay.	This is a failure to Start because the generator was not able to energize the bus	K1 relay was replaced	
20441	S	1	0	0	8/1/2001	S	1	0	0	Control	EDG failed to stabilize its Frequency output while running unloaded during a test.	This is a Start Failure	Governor was repaired	
20522	L	0	1	0	10/8/2001	L	0	1	0	Coolant	EDG was Loaded when a Trouble Alarm annunciated that was caused by lowering Jacket Water Head Tank Level. A Leak from the Jacket Water Pump Seal was found. The Engine ran for 42 minutes of its one hour run.	This is a Load Failure because the EDG would not have completed one hour of Loaded Operation.	Mechanical Seal was replaced	
20541	None	0	0	0	9/30/2001	None	0	0	0	Coolant	EDG 1 Jacket Water Temperature Control Valve Failed Open near the end of a Test Run. This caused a rapid rise in Oil and JW Temperatures. Operator intervention included taking manual control of the Temperature Control valve to reduce temperature to near normal operating limits.	The licensee's analysis determined that if operator actions to control temperture had not been taken, the higher temperatures experienced by the Jacket Water and the Lube Oil would still have been able to support the completion of the EDG Safety Function. Therefore, there is no failure associated with this event.	Temperature Control Valve was repaired.	
20564	None	0	0	0	12/13/2001	None	0	0	0	Control	EDG 23 developed Load Swings while being tested under load, due to a loose wire on the Motor Operated Potentiometer. The test was aborted to perform trouble shooting activities.	Trouble shooting efforts showed that If the EDG was running in Isochronous mode, there would have been no output swings. Therefore, there is no failure with this engine	MOP wire was re-landed and tightened	
20565	None	0	0	0	4/23/2001	S	1	0	0	Engine	EDG 1 inspection showed unexpected wear on Wrist Pins. Wrist Pins were found to have failed due to inadequate lubrication.	None. The inspection detected the condition before it failed to start, load, or run	Engine was rebuilt.	
20578	S	1	0	0	4/26/2000	S	1	0	0	Fuel (Other than transfer)	EDG failed to start following repairs to the Fuel Oil Filter System. Fuel Oil Sediment stirred up in the Fuel Oil Tank prevented the successful start. The sediment was stirred up from Maintenance Activities.	EDG was unavailable to start and run manually or automatically.	Sediment was removed from components and cleaned. Evaluated as indirectly related to the maintenance activity and therefore considered a failure.	
20582	None	0	0	0	8/26/2001	None	0	0	0	Fuel (Other than transfer)	EDG 1 DC Fuel Oil Backup Pump did not Start as expected during a Engine Run. The EDG did start normally via the Shaft Driven Pump, however. A Relay Contact for the DC Pump was determined to have a hair across the mechanism, preventing its movement. Foreign material was subsequently removed.	None - EDG started normally with no Alarms received. DC Pump is a back up pump only.	FME procedures reviewed.	
20776	None	0	0	0	6/14/2001	S	1	0	0	Lube Oil	EDG B Auxiliary Lube Oil Pump Keep Warm Pump became mechanical bound and failed. The pump rebuilt prior to this failure and may have been re-assembled incorrectly.	None. The Pump circulate's Lube Oil through a heater and filter in order to maintain cleanliness and temperature. Loss of this function would not render the EDG unavailable.	Pump Rebuilt	
20856	None	0	0	0	10/3/2000	None	0	0	0	Sequencer	Safety Related Load failed to Load Shed in response to a signal from the Load Shed Relay due to a breaker problem.	Breaker Failure could have prevented EDG from carrying Bus Load.	Breaker Rebuilt	This is a Sequencer issue
20867	None	0	0	0	7/10/2001	None	0	0	0	Ventilation	Fire Dampers for EDG 1/2 C and D Room Air Intake Plenums were found in Closed position with the Blowoff Clip from the Fire Damper Operator Disconnected. This condition rendered Room Ventilation unavailable because the dampers were blocked off.	Both C and D EDGs would Start and Load for approximately 30 minutes prior to tripping due to high room temperature at the time and current temperature of the date of discovery.	Fire Damper Inspections were revised and Blowoff Clips modified.	This is a Room HVAC Issue.

1999 - 2001 EDG Failures

Failure ID	Recommended EDG Failure Mode	Start	Load	Run	Discovery Date	Industry Code	Start	Load	Run	Category	Failure Description	Impact	Corrective Action	Comment
20878	None	0	0	0	11/29/2000	None	0	0	0	Sequencer	B Train Sequencer Logic would not have functioned as required because Inspection Activities found that power supplies were degraded.	Sequencer would not have been available to sequence the loads onto the bus	Sequencer Power Supplies replaced	Sequencer Issue
20969	None	0	0	0	9/17/2001	S	1	0	0	Generator	EDG 2AB failed the restart Test and didn't achieve rated Voltage in less then 10 seconds. It did achieve voltage in slightly over 10 seconds however. The cause was dirty Contacts in the Field Flash Relay.	None. The Generator start was delayed by 3.58 seconds and is not significant.	Field flashing circuit repaired	Field Flash occurred in 13.58 seconds instead of 10 seconds.
20995	None	0	0	0	3/22/2001	S	1	0	0	Control	BOP DG Voltage varied between 450 and 500 Volts. Manual Voltage Control was not effective in adjusting voltage. Potentiometer was found to be degraded.	BOP DG was unavailable for loaded operation	Voltage Regulator was repaired	BOP Generator is not a Safety Related DG
21008	None	0	0	0	8/29/2001	S	1	0	0	Coolant	Essential Service Water Flows were degraded due to Silting. This affected 2AB and 2CD DGs.	Unit 1 and Unit 2 EDGs were unavailable to start and run due to lack of ESW Flow.	DG Heat Exchangers were flushed and flow restored to required rates	This is a ESW Issue and is screened
21168	None	0	0	0	8/6/2001	None	0	0	0	AAC	BOP DG Output Breaker did not close. Further, the breakder did not rack out for trouble shooting. Breaker was found with mechanical linkages disconnected.	BOP DG was unavailable for loaded operation	Breaker was repaired	BOP Generator is not a Safety Related DG
21305	R	0	0	1	10/8/2001	S	1	0	0	Engine	DG Monthly Test was terminated after 1.5 hours of loaded operation because of noise coming from a cylinder and high exhaust temperature. Engine was found to have failed exhaust valve seat inserts.	EDG did not run because it was unable to carry full load after 1 hour.	Engine was rebuilt.	
21317	S	1	0	0	10/21/2001	S	1	0	0	Control	DG Control Power to its logic circuitry was lost during testing. Engine may have not been running at the time, however, it was being prepared for an operations test. Failure occurred when an operator changed a lamp, which shorted inside the lamp receptacle. This in turn caused a control power Fuse to blow.	DG became unavailable and had to be secured. Further, this failure affected the ability for restart, until the control power was restored and components reset.	Short was cleared, fuses replaced, and components were reset.	It is assumed that DG4 was being prepared for an Operations Run when the Fuse Blew.
21322	L	0	1	0	12/13/2001	S	1	0	0	Generator	Although, DG connected to its bus in the required time during an Operations Test, it immediately lost voltage. This failure occured during the ESF Bus during LOOP with ESF Test. The DG did not develop rated Voltage as desired during its starting cycle. A failed Exciter was identified.	DG was unavailable to Load and Run.	Exciter repaired	
21357	None	0	0	0	8/11/2001	None	0	0	0	Sequencer	With EDG 13 removed from service, a Sequencer Malfunction occurred and caused a LOOP on the associated Bus.	Bus E1C was de-energized. The EDG was tagged out of service at this time and was not failed.	Sequencer Power Supplies replaced	Sequencer Issue
21374	L	0	1	0	7/31/2001	S	1	0	0	Control	During Operations Test of EDG A, the Voltage dipped 2 minutes and 30 seconds after Breaker Closure. A failure on the Voltage Regulator was identified.	The engine was secured for repair. EDG A would not have been able to Load.	Voltage Regulator was repaired	
21400	None	0	0	0	12/7/2000	None	0	0	0	AAC	SBO DG Air Compressor would not stop when Receiver reached normal pressure. The SBO DG Computer System failed to stop the Compressor.	None	Computer repaired	SBO Diesel
21581	S	1	0	0	10/17/2001	S	1	0	0	Control	EDG failed to start on Test Signal simulating UV and SI. The EDG went through 3 cranking cycles without a successful start. This left the 1H Emergency Bus de-energized. The EDG's Governor Load Limit was found to be mispositioned. There were further complications with the EDG.	The EDG failed to Start.	The governor was adjusted and a jacket water leak was repaired.	
21616	L	0	1	0	9/16/2001	S	1	0	0	Breaker	25H3 Breaker to 2H Emergency Bus from EDG failed to close while attempting to parallel. An internal Breaker Failure prevented Closure.	The breaker would not have been able to be closed as required to load the EDG. Therefore, this is a Load Failure.	The Breaker, Synch Switch, and Control Switch was replaced.	
21693	L	0	1	0	7/9/2001	S	1	0	0	Engine	EDG shut down from Testing due to Exhauast Leaks. A failed exhaust gasket blew out of the manifold and prevented Turbocharger Operation. This condition rendered the EDG inoperable.	EDG was not available to load	Repaired Exhaust Leaks	

1999 - 2001 EDG Failures

Failure ID	Recommended EDG Failure Mode	Start	Load	Run	Discovery Date	Industry Code	Start	Load	Run	Category	Failure Description	Impact	Corrective Action	Comment
21695	S	1	0	0	10/20/2001	S	1	0	0	Coolant	EDG "Lube Oil Reservoir" Alarm annunciated shortly after it was started for a test. Oil was observed coming from the Vent on the Reservoir and water was visible in the Sightglass. Engine was shutdown. Water was leaking into the Lube Oil Reservoir from a Jacket Water Leak. This occurred prior to paralleling the EDG with the Bus.	EDG was not available for Starting because the EDG Output Breaker was not yet closed.	Repaired Leak	
21745	None	0	0	0	8/17/2001	None	0	0	0	Coolant	Jacket Water Heater became electrically shorted and needed replacement. Heater Circuit became de-energized while EDG was in Standby with the Temperature above 85F.	None - Jacket Water Temperature was always above 85F	Jacket Water Heater Replaced.	
21775	None	0	0	0	5/26/2001	None	0	0	0	Lube Oil	3EC EDG Lube Oil standby circulating keepwarm pump coupling failed.	None - The function of the Circulating Oil Pumps is to supply warmed oil to the Turbocharger and Engine while shutdown to minimize wear during starts.	Pump Rebuilt	
21781	None	0	0	0	10/15/2001	None	0	0	0	Not Applicable	Main Generator failure	None-Main Generator		This is not EDG - Main Generator
21782	S	1	0	0	12/26/2001	S	1	0	0	Breaker	EDG Output Breaker Closing Spring not Charged causing the EDG to be inoperable.	EDG was unavailable for subsequent load. Closing Springs should automatically Charge when breaker is racked up. EDG would Start but not Load.	Breaker Repaired	With Breaker Closing Spring not charged, EDG can NOT carry the bus.
21870	None	0	0	0	7/3/2001	None	0	0	0	Engine	Turbo Charger Hose Leak while running	EDG failed to Load	Repair Hose	This is not a Safety-Related DG
21877	None	0	0	0	4/20/2001	None	0	0	0	Air Start	EDG 33 Air Start Motor ran longer than expected during Test Run. Swagelok Fitting was found sheared off to the Air Start Motor. Additionally, the Air Pressure was higher than expected due to a Regulator problem.	Although the EDG started as required, the failure may have prevented further starts. This condition did not affect the West Air Header	Starting Air problems repaired.	
21879	None	0	0	0	5/4/2001	None	0	0	0	AAC	Appendix R Diesel failed when flames were coming out of its Head Petcock.Engine was secured in 10 minutes after starting.	Engine did not Load	Repaired	Not a safety related EDG
21881	None	0	0	0	5/12/2001	None	0	0	0	Unknown	32 EDG undergoing maintenance activities was manually tripped under full control of the operators.	None - EDG was out of service for related Maintenance	None - Maintenance Activities were in progress	Shutdown was precautionary
21894	None	0	0	0	6/15/2001	None	0	0	0	Lube Oil	33 DG Pre Lube Pump was not running in Standby.MCC 39 feeder to EDG Auxiliaries was deengergized. EDG was declared inoperable and secured from standby because it under 120 F. Subsequently the EDG was run, to bring temperature up and was declared operable.	None- EDG would have started and run.	MCC fuses were replaced.	
21912	L	0	1	0	10/16/2001	L	0	1	0	Control	Speed Switch failed on EDG Start which caused its tripping on Reverse Power. The EDG was loaded for a short period of time prior to the tirp.	Failure to Load.	Speed Switches were replaced	
21943	None	0	0	0	12/4/2000	S	1	0	0	Control	EDG 1-3 failed to stabilize Voltage in less than 13 seconds as requied. Instead it stabilized in 13.58 seconds. The Motor Operated Potentiometer was adjusted and the engine passed criteria.	None- EDG would have started and run.	MOP was adjusted	
21949	None	0	0	0	7/3/2001	None	0	0	0	AAC	Appendix R DG jacket water heater was energized while engine was being drained for maintenance.	None - DG was in Maintenance	None	Appears to be a duplicate of 18075.
22001	S	1	0	0	6/21/2001	S	1	0	0	Control	EDG Speed Switch was found with loose screws while EDG was in Standby. When touched, the Overspeed Trip, locked out the Engine which became unavailable for Starting.	Engine was unable to Start	Speed Switch was repaired	
22150	None	0	0	0	9/12/2001	None	0	0	0	Not Applicable	Lighting UPS Ballast failed	None	Replaced Ballast	Not a EDG Failure
22158	None	0	0	0	2/19/2001	S	1	0	0	Control	EDG 1-2 failed to reach 900 RPM in 10 Seconds during Operations Test. Fuel system and Governor needed adjustment.	None - Engine was only 0.162 Seconds out of specification	Adjusted Fuel Component Settings.	
22249	None	0	0	0	4/5/2001	None	0	0	0	Not Applicable	Control Room Lighting UPS Inverter Blower B1 not running.	None	None	Not DG Related

1999 - 2001 EDG Failures

Failure ID	Recommended EDG Failure Mode	Start	Load	Run	Discovery Date	Industry Code	Start	Load	Run	Category	Failure Description	Impact	Corrective Action	Comment
22309	None	0	0	0	10/12/2001	S	1	0	0	Control	EDG A SW Bypass Valve failed to close when handswitch was taken to Close. This caused to EDG to be declared Inoperable.	None - This condition would not preclude DG Start, Load, or Run	Handswitch repaired	Requirement for SW Separation is Administrative and had no effect on ability of EDG to start
22325	None	0	0	0	11/15/2000	S	1	0	0	Fuel Transfer	DFOTP1 Diesel Fuel Oil Transfer Pump 0-1 was selected to ON in order to recirculate the tank for sampling. Pump began to cycle on and off intermittently. High Resistance was found across Relay 49-1H-65.	None - FOTP ran steadily with operator intervention. Intermittent operation did not appear to be enough to prevent adequate fuel supply.	Contactors Cleaned on Relay 49-1H-65	
22363	None	0	0	0	6/29/2001	None	0	0	0	Not Applicable	CR Battery Lighting UPS failed to power lighting for the full 4 hours as required.	None	NA	Not DG Related
22557	None	0	0	0	9/22/2001	None	0	0	0	Not Applicable	AC Supply Breaker to 1-IV Battery Charger Tripped just after placing Charger in service.	None	NA	Not DG Related
22561	L	0	1	0	10/17/2001	S	1	0	0	Engine	EDG experienced Water/Oil Mixture coming out of Crankcase Air Box Drain during a Test Run. The Test was halted. A failed Plug was found on Cylinder #19.	This is a Failure to Load because the Test was secured prior to one hour of loaded operation.	Plug on Cylinder 19 was replaced	
22568	None	0	0	1	9/26/2001	S	1	0	0	Fuel Transfer	Fuel Oil Transfer Pump Discharge RV leaking grossly, so that pump would not pump fuel oil to the U2 "H" EDG day tank. Pump was able to pump with operator intervention by manipulating the relief valve.	None - FOTP ran steadily with operator intervention	Pump Rebuilt	
22573	S	1	0	0	11/17/2001	S	1	0	0	Control	EDG failed to start during Testing due to failed START Relay 1. STR 1 did not allow Air Start Solenoid to Energize.	This is a Start Failure	STR1 was replaced.	
22583	L	0	1	0	10/17/2001	S	1	0	0	Engine	EDG had to be shutdown during loaded testing due to noise coming from the Scavenging Air System. Test was aborted prior to one hour of loaded operation. Fuel Rack was also found to be hunting.	This is a Load Failure	Found several mechanical problems and repaired	
22619	None	0	0	0	9/19/2001	S	1	0	0	Air Start	EDG B failed to start on one Air Start System Train. SOV DG-23B malfunctioned. EDG B started successfully on the opposite Air Start System Train.	None- EDG would have started and run on the opposite Starting Air System Train.	Replaced SOV DG-23B	
22824	None	0	0	0	9/25/2001	None	0	0	0	Not Applicable	DEG-0-1032 Check Valve for the DG Fuel XFR Pump Vault Floor Drain Check Valve was inspected and found to be on the closed position, however, it was stuck in the closed direction due to buildup of deposits.	Drain Check Valve prevents room flooding and does not affect EDG operation, therefore, the is No Failure	Valve was cleaned	
23557	L	0	1	0	12/11/2001	S	1	0	0	Lube Oil	EDG loaded but needed to be shutdown due to a Governor Oil Leak	EDG failed to Load	Oil Leak was repaired	This is a Failure to Load
23659	None	0	0	0	12/11/2001	None	0	0	0	Ventilation	EDG D1 Room Ventilation Failed to Start during EDG Surveillance Test. Operators locally started fans which ran successfully. The 14X/D1 relay was replaced.	Had operators not intervened, the room temperature may have risen to where the EDG would trip on temperature related causes.	Relay was replaced	This is a HVAC issue
23691	None	0	0	0	11/14/2001	S	1	0	0	Control	EDG Voltage Regulator was damaged by Test Equipment improperly hooked up electronically. This shorted a power supply to a Voltage Regulator circuit.	EDG was out of service for several days thereafter, for repairs.	Repaired faulted electrical components	Maintenance-related failure. The test equipment caused the EDG to be unavailable for several days
23699	L	0	1	0	11/28/2001	L	0	1	0	Unknown	EDG tripped due to High Crankcase Pressure during Monthly Test. EDG was Loaded for Less than one hour.	This is a Failure to Load because the Test was secured prior to one hour of loaded operation.	Cause of the Crankcase pressure was repaired after extensive troubleshooting.	
24086	None	0	0	0	8/23/2001	None	0	0	0	AAC	Conowingo Dam Breaker to SBO Bus Tripped.	None - not a EDG	SBO SWGR Repaired	Not a safety related EDG
24139	S	1	0	0	10/30/2001	L	0	1	0	Coolant	EDG Tripped on Low Jacket Cooling Water Pressure, during Testing. Cause was valve mispositioning error. The JW Cooling Headtank isolation Valve was closed and should have been open.	This is a Start Failure as the EDG was not yet Paralleled to the Bus. The licensee stated that no power was lost.	Conducted investigation to the cause of the Valve Mispositioning Event	
24322	None	0	0	0	9/7/2001	None	0	0	0	Not Applicable	This event describes the shared response to RIS 2000-24 between NMP and Fitzpatrick Offsite Power and Grid Reliabilities studies.	None - not a EDG	None	
24573	None	0	0	0	7/26/1999	S	1	0	0	Control	Control Panel Module failed to annunciate a EDG Trouble Alarm in the Control Room in response to Local Panel Alarm "Lo Air Pressure" TEST.	None - Alarm Function Only. The Alarm Test did not render the EDG unavailable.	Repaired Module	

1999 - 2001 EDG Failures

Failure ID	Recommended EDG Failure Mode	Start	Load	Run	Discovery Date	Industry Code	Start	Load	Run	Category	Failure Description	Impact	Corrective Action	Comment
24576	None	0	0	0	7/26/2000	S	1	0	0	Control	Control Panel Module failed to annunciate a EDG Trouble Alarm in the Control Room in response to Local Panel Alarm "Lo Air Pressure" TEST.	None - Alarm Function Only. The Alarm Test did not render the EDG unavailable.	Repaired Module	
24659	L	0	1	0	12/26/2001	L	0	1	0	Lube Oil	0EDG Locked Out on Low Lube Oil Pressure even though adequate oil pressure existed. Tubing was inadequate to transmit the pressure to Pressure Switch.	EDG failed to Load	Installed Larger Tubing	
24702	S	1	0	0	12/11/2001	S	1	0	0	Control	Malfunctioning Speed Switch caused Overspeed Trip Signal with EDG in Standby.	This is a Start Failure	Replaced Speed Switch	
24766	None	0	0	0	5/22/2001	None	0	0	0	Not Applicable	Breaker Tripped from voltage fluctuation do to a Lightning Strike.	None - not a EDG	None - Not a EDG	
24787	None	0	0	0	12/23/1999	S	1	0	0	Control	Local Panel did not Alarm Test Correctly. This is Alarm Function only	None - Did not cause a EDG Failure	Repaired Panel	
24788	None	0	0	0	3/9/2000	S	1	0	0	Control	Local Panel did not Alarm Test Correctly. This is Alarm Function only	None - Did not cause a EDG Failure	Repaired Panel	
24789	None	0	0	0	7/5/2000	S	1	0	0	Control	Local Panel did not Alarm Test Correctly. This is Alarm Function only	None - Did not cause a EDG Failure	Repaired Panel	
24790	None	0	0	0	8/19/2001	S	1	0	0	Control	Local Panel did not Alarm Test Correctly. This is Alarm Function only	None - Did not cause a EDG Failure	Repaired Panel	
25440	None	0	0	0	10/13/2000	None	0	0	0	Not Applicable	Misoperation of electrical bus line ups caused inadvertent ESF Actuation and Auto Start of Component Cooling Water Pump 1-1	None- Did not cause a EDG Failure	Stabilized plant and secured from errant Line Up.	
25617	None	0	0	0	11/26/2001	None	0	0	0	Not Applicable	RCP 1A Overcurrent Relays found out of tolerance.	None - Did not cause a EDG Failure	Calibrated Overcurrent Relays	
25871	None	0	0	0	6/26/2000	None	0	0	0	Not Applicable	Alternate Sources of Offsite AC were not available to be controlled from the Control Room, as designed. Instead, the Transmission Control Center had control of the breakers due to misunderstanding of responsiblities.	None - Did not cause a EDG Failure	Revised TCC procedures	
26533	R	0	0	1	5/1/2001	S	1	0	0	Fuel Transfer	EDG Fuel Oil Day Tank Level was Low, during EDG Endurance Run. Fuel Oil Transfer Pump malfunctioned causing Low level in Day Tank. Pump had a Failed RV.	EDG would not have been able to Run over one hour of loaded operation with the Failed Transfer Pump	FOTP was repaired.	Day Tank Level was dropping 4" per hour. Day Tank had 25" in it when test started. EDG would not have been able to run for greater than 4 hours. NEI review recommended removal of this failure. As new guidance for the inclusion of the FOTP would count this failure, the failure is retained.
26561	None	0	0	0	12/5/1999	None	0	0	0	Lube Oil	OC DG Prelube Pump Breaker was found open and its indication not illuminated. The cause of this was a blown fuse in the Breaker Control Power Circuit.	None - Prelube Pump Loss did not affect the EDG Availability.	Short Circuit was traced to lamp socket	Prelube Pump is used for Slow Speed start - OC DG is an alternate AC diesel.
27306	L	0	1	0	4/15/2000	S	1	0	0	Control	While Operating EDG For Surveillance Testing an acrid burning odor coming from the EDO control panel was detected. The Linear Reactor in the Exciter circuit was found grounded. Although this did not cause any operation problems, the degraded condition of the Reactor caused operations to shut down the engine.	This is a Load Failure because the engine was shutdown in less than one hour of loaded operation.	Repaired Linear Reactor	
27924	L	0	1	0	6/2/2000	L	0	1	0	Coolant	EDG Tripped on Low Jacket Coolant Pressure in the first 20 minutes of loaded run. The test was an endurance run. A failed Jacket Water Coolant pump seal was identified	Engine was unavailable for Loading and Running	Replaced JW Cooling Pump	
28504	R	0	0	1	10/31/2000	S	1	0	0	Lube Oil	EDG surveillance run had to be terminated after several hours of operation due to high Lube Oil Strainer Differential Pressure. Unusual amounts of Lube Oil Debris were identified due to engine cylinder and piston wear in excess of what was expected.	Engine would not have been available for Running. This is assumed because of the Piston and Cylinder damage, not the Lube Oil Strainer DP.	Unknown	Assumed that Operators could swap Lube Oil Strainers during Engine Run. In this case, EDG could run longer.
29130	S	1	0	0	8/8/2001	None	0	0	0	Control	EDG started for no apparent reason. There was an problem in the Control Relay Panel.	Assuming that the failure affected the Start Logic, this event is conservatively evaluated as a Start Failure	Unknown	Assuming that this event is a Start Failure due to lack of detailed information and that it affected the Starting Logic.

1999 - 2001 EDG Failures

Failure ID	Recommended EDG Failure Mode	Start	Load	Run	Discovery Date	Industry Code	Start	Load	Run	Category	Failure Description	Impact	Corrective Action	Comment
31883	None	0	0	0	8/31/2001	None	0	0	0	Sequencer	UV Bistable found with degraded Deadband.	None - Bistable although degraded, was able to function.	Bistable replaced.	Sequencer Issue
34546	L	0	1	0	12/14/1999	S	1	0	0	Engine	Prior to Running, EDG was found with a broken Bearing Bullseye Oil Detector. Test was post-poned until after maintenance.	This would have prevented the EDG from operating for an extended period. Therefore, this is conservatively identified as a Load Failure	Bullseye was repaired	
34548	None	0	0	0	8/12/1999	None	0	0	0	Ventilation	EDG 2A-A had a failed Room HVAC Damper Link which would have caused unavailability. The Fire Protection CO2 Thermal Link failed causing closure of the Damper.	This condition could have caused room temperature to rise to tripping point IF EDG were in operation. Because there is no alarm on the closed fire damper, this event is conservatively identified as Start Failure.	Link Replaced	This event is screend as it is an HVAC event.
34586	S	1	0	0	11/13/2001	S	1	0	0	Control	EDG failed to start from Local Control. The Time Delay relays were found with tight tolerances incompatible with actual engine performance requirements.	Start Failure	Time delays for the relays were calibrated	
37226	S	1	0	0	11/14/2000	None	0	0	0	Coolant	EDG Jacket Water Leaked into Lube Oil. Leakage was from the Lube Oil Ht Exchanger Floating Packing Head Connection. Significant amount of water was found in Lube Oil. This condition was identified during routine Maintenance.	Significant Damage could have ocurred if EDG was ran. This is a start faiure.	Heat Exchanger was rebuilt.	It is assumed that the Maintenance Activities were unrelated to repairing the Heat Exchanger.
37310	R	0	0	1	5/9/2001	S	1	0	0	Engine	DG was prematurely shutdown due to increasing crankcase pressure prior to it reaching the trip set-point. Causes of the hi-crankcase pressure include a change in Fuel Oil type and Lube Oil Problems.	The DG would not have been able to Run. It is assumed that the DG ran loaded for greater than 1 hour.	Investigation inconclusive	

Appendix B

EDG Success Data

EDG Success Data

DeviceID	Test Start Demands	Operation Start Demands	Total Start Demands	Avg Starts / Month	Test Load Demands	Operation Load Demands	Total Load Demands	Avg Load Run / Start	Test Run Hours	Operation Run Hours	Total Run Hours	Run - Load Run Hours	Comments
28468	42	4	46	1.3	61	4	65	1.5	153.45	7.61	161.06	96.06	Actual
92	38	5	43	1.2	59	5	64	1.6	193.31	8.26	201.57	137.57	Actual
30727	60		60	1.7	50		50	0.8	124.01		124.01	74.01	Actual
54598	51		51	1.4	44		44	0.9	109.52		109.52	65.52	Actual
64497	46		46	1.3	44		44	1.0	69		69	25	Actual
64832	49		49	1.4	46		46	0.9	72		72	26	Actual
70252	47	2	49	1.4	45	1	46	1.0	70.5	20	90.5	44.5	Actual
71036	43		43	1.2	41		41	1.0	64.5		64.5	23.5	Actual
75429	36	22	58	1.6	42	24	66	1.2	148.71	96.82	245.53	179.53	No Load Run data recorded for 1999 - 2001. Used 200301 - 200512,
75430	37.43	32	69.43	1.9	44	26	70	1.2	121.22	121.16	242.38	172.38	No Load Run data recorded for 1999 - 2001. Used 200301 - 200512,
103913	47.47	30	77.47	2.2	43	24	67	0.9	143.46	123.68	267.14	200.14	No Load Run data recorded for 1999 - 2001. Used 200301 - 200512,
103804	62.64	28	90.64	2.5	43	18	61	0.7	102.11	134.58	236.69	175.69	Actual
124217	56		56	1.6	46		46	0.8	95		95	49	Estimated per 36 months - effective 200201
920861	53		53	1.5	45		45	0.8	88.4		88.4	43.4	Estimated per 36 months - effective 200201
124306	57		57	1.6	44		44	0.8	94.6		94.6	50.6	Estimated per 36 months - effective 200201
124307	54		54	1.5	46		46	0.9	118.7		118.7	72.7	Estimated per 36 months - effective 200201
129113	52		52	1.4	46		46	0.9	95.2		95.2	49.2	Estimated per 36 months - effective 200201
129112	52		52	1.4	45		45	0.9	92.8		92.8	47.8	Estimated per 36 months - effective 200201
129115	60		60	1.7	51		51	0.9	117.1		117.1	66.1	Estimated per 36 months - effective 200201
129117	56	1	57	1.6	48	1	49	0.9	122.7	0.63	123.33	74.33	Estimated per 36 months - effective 200201
138701	40.5	8	48.5	1.3	37.5	2	39.5	0.9	256.5	21.6	278.1	238.6	Estimated per 24 months - effective 200101
138703	40.5	8	48.5	1.3	27.5	2	29.5	0.7	256.5	10.1	266.6	237.1	Estimated per 24 months - effective 200101
138705	40.5	8	48.5	1.3	27.5		27.5	0.7	256.5	13.42	269.92	242.42	Estimated per 24 months - effective 200101
138707	40.5	8	48.5	1.3	27.5		27.5	0.7	256.5	14.02	270.52	243.02	Estimated per 24 months - effective 200101
144445	72		72	2.0	60		60	0.8	216		216	156	Estimated per 12 months - effective 199701
144447	72		72	2.0	60		60	0.8	216		216	156	Estimated per 12 months - effective 199701
149279	72		72	2.0	60		60	0.8	216		216	156	Estimated per 12 months - effective 199701
149281	72		72	2.0	60		60	0.8	216		216	156	Estimated per 12 months - effective 199701
154071	66		66	1.8	66		66	1.0	66		66	0	Estimated per 18 months - effective 200301
154072	76		76	2.1	76		76	1.0	76		76	0	Estimated per 18 months - effective 200301
159750	74		74	2.1	51		51	0.7	92		92	41	Actual
159126	52		52	1.4	49		49	0.9	80.2		80.2	31.2	Actual
163626	55		55	1.5	44		44	0.8	93.7		93.7	49.7	Actual
163078	54		54	1.5	48		48	0.9	101.8		101.8	53.8	Actual
166779	46		46	1.3	46		46	1.0	214.3		214.3	168.3	Actual
166780	47		47	1.3	42		42	0.9	192.5		192.5	150.5	Actual
173053	49		49	1.4	47		47	1.0	160.6		160.6	113.6	Actual
172652	67		67	1.9	59		59	0.9	231.3		231.3	172.3	Actual
178388	51	1	52	1.4	42	1	43	0.8	169.44	8.6	178.04	135.04	Estimated per 24 months - effective 200301
178752	52.5	1	53.5	1.5	42	1	43	0.8	214.35	9.3	223.65	180.65	Estimated per 24 months - effective 200301
185770	44		44	1.2	43		43	1.0	137.63		137.63	94.63	Estimated per 36 months - effective 200301
185526	44		44	1.2	44		44	1.0	41.4		41.4	-2.6	Estimated per 36 months - effective 200301
191043	76		76	2.1	70		70	0.9	206		206	136	Estimated per 18 months - effective 200301
190618	72		72	2.0	70		70	1.0	200		200	130	Estimated per 18 months - effective 200301
196783	72	1	73	2.0	70	1	71	1.0	194	7.35	201.35	130.35	Estimated per 18 months - effective 200301
197074	68		68	1.9	66		66	1.0	184		184	118	Estimated per 18 months - effective 200301
250005	63.6		63.6	1.8	58.8		58.8	0.9	276.4		276.4	217.6	Load-run estimated per 30 months - effective 200301, run estimated per 20 months -effective 199703
246629	52.8	1	53.8	1.5	48		48	0.9	267.1		267.1	219.1	Load-run estimated per 30 months - effective 200301, run estimated per 20 months -effective 199703
262755	42	3	45	1.3	43	2	45	1.0	158.45	7.5	165.95	120.95	Actual
262756	47	4	51	1.4	42	4	46	0.9	160.3	1	161.3	115.3	Actual
269404	49	11	60	1.7	39	1	40	0.8	99.13	5.35	104.48	64.48	Actual
268257	45	17	62	1.7	41	3	44	0.9	94.85	8.39	103.24	59.24	Actual
272113	54.8	6	60.8	1.7	42.3	1	43.3	0.8	87.7	37.28	124.98	81.68	Estimated per 23 months - effective 200207
272071	120	3	123	3.4	56	1	57	0.5	296.44	39.06	335.5	278.5	Based on 9 months (199901,04,,07)

EDG Success Data

DeviceID	Test Start Demands	Operation Start Demands	Total Start Demands	Avg Starts / Month	Test Load Demands	Operation Load Demands	Total Load Demands	Avg Load Run / Start	Test Run Hours	Operation Run Hours	Total Run Hours	Run - Load Run Hours	Comments
272072	132	4	136	3.8	68	1	69	0.5	251.68	41.12	292.8	223.8	Based on 9 months (199901,04,,07)
276584	52	3	55	1.5	40		40	0.8	65.68	4.07	69.75	29.75	Based on 9 months (199901,04,,07)
276585	92.57	3	95.57	2.7	48		48	0.5	162.9	6.02	168.92	120.92	Estimated per 21 months - effective 200301
276858	85.7	3	88.7	2.5	53.1		53.1	0.6	176.6	8.14	184.74	131.64	Estimated per 21 months - effective 200301
201637	44		44	1.2	40		40	0.9	104		104	64	Estimate per 18 months - effective 200101
201638	44	2	46	1.3	40	4	44	0.9	104	4.28	108.28	64.28	Estimate per 18 months - effective 200101
202801	44		44	1.2	40		40	0.9	104		104	64	Estimate per 18 months - effective 200101
202802	44	1	45	1.3	40	1	41	0.9	104	2.05	106.05	65.05	Estimate per 18 months - effective 200101
281254	115.2	2	117.2	3.3	115.2		115.2	1.0	411.3	5.6	416.9	301.7	Estimated per 20 months - effective 199703. Start demands assumed equal to load runs
281253	48.6		48.6	1.4	48.6		48.6	1.0	171.7		171.7	123.1	Estimated per 20 months - effective 199703. Start demands assumed equal to load runs
285123	54	1	55	1.5	54		54	1.0	80	2.53	82.53	28.53	Estimated per 18 months - effective 199705. Start demands assumed equal to load runs
292556	48.75	10	58.75	1.6	42	10	52	0.9	101.41	10	111.41	59.41	Estimated per 48 months - effective 200201. Run data actual.
293925	52.5	10	62.5	1.7	42	10	52	0.8	101.55	10.2	111.75	59.75	Estimated per 48 months - effective 200201. Run data actual.
373820	55		55	1.5	45		45	0.8	111.68		111.68	66.68	Actual
373380	49		49	1.4	44		44	0.9	103.83		103.83	59.83	Actual
373369	57		57	1.6	44		44	0.8	108.57		108.57	64.57	Actual
378663	57		57	1.6	53		53	0.9	103.19		103.19	50.19	Actual
378777	47		47	1.3	49		49	1.0	110.93		110.93	61.93	Actual
294268	97		97	2.7	70		70	0.7	155		155	85	Actual
294265	89		89	2.5	59		59	0.7	151		151	92	Actual
294266	104		104	2.9	58		58	0.6	138		138	80	Actual
299053	81		81	2.3	58		58	0.7	140		140	82	Actual
305131	60	3	63	1.8	59	3	62	1.0	196.15	5.9	202.05	140.05	Actual
305200	62	1	63	1.8	51	1	52	0.8	176.92	3.2	180.12	128.12	Actual
305133	55		55	1.5	54		54	1.0	177.46		177.46	123.46	Actual
305202	62		62	1.7	57		57	0.9	205		205	148	Actual
315455	70	1	71	2.0	45	1	46	0.6	136.4	0.5	136.9	90.9	Actual
315392	82	1	83	2.3	43	1	44	0.5	121.1	0.7	121.8	77.8	Actual
323887	84		84	2.3	49		49	0.6	236.4		236.4	187.4	Actual
324067	80		80	2.2	49		49	0.6	168.09		168.09	119.09	Actual
713103	48	7	55	1.5	48	7	55	1.0	240	39.3	279.3	224.3	Estimated per 18 months - effective 200101
713379	48	9	57	1.6	48	9	57	1.0	240	11.4	251.4	194.4	Estimated per 18 months - effective 200101
384243	54		54	1.5	52		52	1.0	285.14		285.14	233.14	Estimated per 18 months - effective 199707
384680	52		52	1.4	52		52	1.0	193.44		193.44	141.44	Estimated per 18 months - effective 199707
384249	46		46	1.3	46		46	1.0	177.72		177.72	131.72	Estimated per 18 months - effective 199707
384251	48		48	1.3	46		46	1.0	140.42		140.42	94.42	Estimated per 18 months - effective 199707
390338	51	24	75	2.1	51	18	69	1.0	111	37.91	148.91	79.91	Estimated per 24 months - effective 200301
390359	60	35	95	2.6	60	33	93	1.0	90	22.25	112.25	19.25	Estimated per 24 months - effective 199807
390342	45	35	80	2.2	45	32	77	1.0	108	25.2	133.2	56.2	Estimated per 24 months - effective 199807
394357	46		46	1.3	42		42	0.9	80.09		80.09	38.09	Actual
394359	50		50	1.4	43		43	0.9	80.47		80.47	37.47	Actual
394291	53		53	1.5	44		44	0.8	79.16		79.16	35.16	Actual
309388	89		89	2.5	101		101	1.1	95.51		95.51	-5.49	Estimated per 26 months - effective 200301
309446	89		89	2.5	101		101	1.1	97.21		97.21	-3.79	Estimated per 26 months - effective 200301
309390	89		89	2.5	104		104	1.2	101.47		101.47	-2.53	Estimated per 26 months - effective 200301
309392	97		97	2.7	104		104	1.1	109.08		109.08	5.08	Estimated per 26 months - effective 200301
399159	51		51	1.4	43		43	0.8	232.02		232.02	189.02	Actual
399176	54		54	1.5	41		41	0.8	249.56		249.56	208.56	Actual
402984	68	1	69	1.9	52	2	54	0.8	137.69	22.02	159.71	105.71	Actual
402986	61		61	1.7	41		41	0.7	127.35		127.35	86.35	Actual
408836	67		67	1.9	52		52	0.8	146.71		146.71	94.71	Actual
413910	30		30	0.8	49.5		49.5	1.7	53.25		53.25	3.75	Estimated per 24 months - effective 199611. Startt demand were shown as 2 per 24 months. This appears to be an error as more recent data shows monthly testing. Assumed 20 per 24 months.

EDG Success Data

DeviceID	Test Start Demands	Operation Start Demands	Total Start Demands	Avg Starts / Month	Test Load Demands	Operation Load Demands	Total Load Demands	Avg Load Run / Start	Test Run Hours	Operation Run Hours	Total Run Hours	Run - Load Run Hours	Comments
414093	30		30	0.8	49.5		49.5	1.7	53.25		53.25	3.75	Estimated per 24 months - effective 199611. Startt demand were shown as 2 per 24 months. This appears to be an error as more recent data shows monthly testing. Assumed 20 per 24 months.
414094	30		30	0.8	49.5		49.5	1.7	53.25		53.25	3.75	Estimated per 24 months - effective 199611. Startt demand were shown as 2 per 24 months. This appears to be an error as more recent data shows monthly testing. Assumed 20 per 24 months.
413911	30		30	0.8	49.5		49.5	1.7	53.25		53.25	3.75	Estimated per 24 months - effective 199611. Startt demand were shown as 2 per 24 months. This appears to be an error as more recent data shows monthly testing. Assumed 20 per 24 months.
420673	30		30	0.8	49.5		49.5	1.7	53.25		53.25	3.75	Estimated per 24 months - effective 199611. Startt demand were shown as 2 per 24 months. This appears to be an error as more recent data shows monthly testing. Assumed 20 per 24 months.
420941	30		30	0.8	49.5		49.5	1.7	53.25		53.25	3.75	Estimated per 24 months - effective 199611. Startt demand were shown as 2 per 24 months. This appears to be an error as more recent data shows monthly testing. Assumed 20 per 24 months.
420943	30		30	0.8	49.5		49.5	1.7	53.25		53.25	3.75	Estimated per 24 months - effective 199611. Startt demand were shown as 2 per 24 months. This appears to be an error as more recent data shows monthly testing. Assumed 20 per 24 months.
420945	30		30	0.8	49.5		49.5	1.7	53.25		53.25	3.75	Estimated per 24 months - effective 199611. Startt demand were shown as 2 per 24 months. This appears to be an error as more recent data shows monthly testing. Assumed 20 per 24 months.
426106	78		78	2.2	49		49	0.6	206.9		206.9	157.9	Actual
425897	83		83	2.3	56		56	0.7	193.9		193.9	137.9	Actual
431267	70		70	1.9	46		46	0.7	214.5		214.5	168.5	Actual
431268	76		76	2.1	49		49	0.6	222.6		222.6	173.6	Actual
440377	30	1	31	0.9	45		45	1.5	185.4		185.4	140.4	Actual
440379	25		25	0.7	41		41	1.6	194.06		194.06	153.06	Actual
444272	10		10	0.3	50		50	5.0	142.94		142.94	92.94	Actual
444340	10		10	0.3	55		55	5.5	153.65		153.65	98.65	Actual
450139	45		45	1.3	42		42	0.9	80.88		80.88	38.88	Actual
449718	48		48	1.3	48		48	1.0	100.32		100.32	52.32	Actual
736429	56	1	57	1.6	51	1	52	0.9	261.5	35.48	296.98	244.98	No data recorded for 1999 - 2001. Used 200201 - 200412,
736430	59	1	60	1.7	57	1	58	1.0	277.53	39.17	316.7	258.7	No data recorded for 1999 - 2001. Used 200201 - 200412,
453530	44	1	45	1.3	40	1	41	0.9	52.11	9.16	61.27	20.27	Actual
453794	37	9	46	1.3	35	7	42	0.9	63.31	34.64	97.95	55.95	Actual
456878	43.9	11	54.9	1.5	37.9	2	39.9	0.9	176.8	9.77	186.57	146.67	Estimated per 20 months - effective 199610
456879	43.9	14	57.9	1.6	37.9	11	48.9	0.9	161.8	34.34	196.14	147.24	Estimated per 20 months - effective 199610
518352	44	1	45	1.3	44	1	45	1.0	122		122	77	Estimated per 18 months - effective 199701
511898	44	1	45	1.3	44	3	47	1.0	122	12.27	134.27	87.27	Estimated per 18 months - effective 199701
572985	44		44	1.2	44		44	1.0	122		122	78	Estimated per 18 months - effective 199701
534562	44		44	1.2	44		44	1.0	122		122	78	Estimated per 18 months - effective 199701
590380	119	1	120	3.3	97	1	98	0.8	131.8	3.4	135.2	37.2	Actual
590381	108		108	3.0	89		89	0.8	127.7		127.7	38.7	Actual
593097	60	12	72	2.0	60	5	65	1.0	300	450.56	750.56	685.56	Estimated per 18 months - effective 200101
593098	60	11	71	2.0	60	6	66	1.0	300	453.75	753.75	687.75	Estimated per 18 months - effective 200101

EDG Success Data

DeviceID	Test Start Demands	Operation Start Demands	Total Start Demands	Avg Starts / Month	Test Load Demands	Operation Load Demands	Total Load Demands	Avg Load Run / Start	Test Run Hours	Operation Run Hours	Total Run Hours	Run - Load Run Hours	Comments
596679	50	28	78	2.2	50	28	78	1.0	271.03	9.25	280.28	202.28	Estimated per 36 months - effective 200101
596680	49	23	72	2.0	49	23	72	1.0	262.83	8.8	271.63	199.63	Estimated per 36 months - effective 200101
603103	50	28	78	2.2	50	28	78	1.0	271.03	9.25	280.28	202.28	Estimated per 36 months - effective 200101
603104	49	23	72	2.0	49	23	72	1.0	262.83	8.8	271.63	199.63	Estimated per 36 months - effective 200101
610313	50	28	78	2.2	50	28	78	1.0	271.03	9.25	280.28	202.28	Estimated per 36 months - effective 200101
610315	49	23	72	2.0	49	23	72	1.0	262.83	8.8	271.63	199.63	Estimated per 36 months - effective 200101
615673	178.5	22	200.5	5.6	88.5	4	92.5	0.5	189	9.5	198.5	106	Estimated per 24 months - effective 200304
615674	178.5	14	192.5	5.3	88.5		88.5	0.5	189	1.66	190.66	102.16	Estimated per 24 months - effective 200304
615675	178.5	12	190.5	5.3	88.5	4	92.5	0.5	189	9	198	105.5	Estimated per 24 months - effective 200304
615676	178.5	10	188.5	5.2	88.5		88.5	0.5	189	2	191	102.5	Estimated per 24 months - effective 200304
626613	71		71	2.0	54		54	0.8	96.54		96.54	42.54	Actual
626615	77		77	2.1	62		62	0.8	83.34		83.34	21.34	Actual
632139	41	1	42	1.2	39	1	40	1.0	64.08	7.22	71.3	31.3	Actual
632109	43	1	44	1.2	39	1	40	0.9	62.1	8.53	70.63	30.63	Actual
635704	36	2	38	1.1	36	2	38	1.0	132.6		132.6	94.6	Estimated per 12 months - effective 200101
635653	36	2	38	1.1	36	2	38	1.0	103.5		103.5	65.5	Estimated per 12 months - effective 200101
635812	36	2	38	1.1	36	2	38	1.0	161.7		161.7	123.7	Estimated per 12 months - effective 200101
635811	36		36	1.0	36		36	1.0	225.9		225.9	189.9	Estimated per 12 months - effective 200101
641686	39		39	1.1	39		39	1.0	168.53		168.53	129.53	Actual
641679	35		35	1.0	35		35	1.0	160.73		160.73	125.73	Actual
645367	39	14	53	1.5	41	2	43	1.1	170.48	3	173.48	130.48	Actual
645606	50		50	1.4	45		45	0.9	233.24		233.24	188.24	Actual
648766	100.4	2	102.4	2.8	66.3	2	68.3	0.7	75.8	5.34	81.14	12.84	Estimated per 19 months - effective 199706
648777	132.6		132.6	3.7	36		36	0.3	43.6		43.6	7.6	Estimated per 19 months - effective 199706
653988	81.5	3	84.5	2.3	36	2.5	38.5	0.4	43.6	2.97	46.57	8.07	Estimated per 19 months - effective 199706
319512	40	2	42	1.2	40		40	1.0	40		40	0	Estimated per 18 months - effective 199701
319513	40		40	1.1	40		40	1.0	40		40	0	Estimated per 18 months - effective 199701
707056	103	1	104	2.9	80	1	81	0.8	240.75	1.03	241.78	160.78	Actual
656958	77		77	2.1	68		68	0.9	196.66		196.66	128.66	Actual
716627	72	2	74	2.1	51	2	53	0.7	152.4	3.07	155.47	102.47	Estimated per 36 months - effective 200201
716195	65	2	67	1.9	54	2	56	0.8	142.4	3	145.4	89.4	Estimated per 36 months - effective 200201
716626	75	2	77	2.1	55	2	57	0.7	136.3	2.97	139.27	82.27	Estimated per 36 months - effective 200201
720261	61	2	63	1.8	49	2	51	0.8	122.2	3.6	125.8	74.8	Estimated per 36 months - effective 200201
720262	63	2	65	1.8	51	2	53	0.8	139.5	2.73	142.23	89.23	Estimated per 36 months - effective 200201
720709	68	2	70	1.9	54	2	56	0.8	131.7	3.48	135.18	79.18	Estimated per 36 months - effective 200201
724718	62		62	1.7	60		60	1.0	150		150	90	Estimated per 36 months - effective 199801
724771	66		66	1.8	64		64	1.0	137		137	73	Estimated per 36 months - effective 199801
731388	59		59	1.6	57		57	1.0	135		135	78	Estimated per 36 months - effective 199801
731367	62		62	1.7	60		60	1.0	129		129	69	Estimated per 36 months - effective 199801
926916	53	4	57	1.6	42		42	0.8	136.8	17.5	154.3	112.3	Actual
926917	49	4	53	1.5	41		41	0.8	82.8	17.06	99.86	58.86	Actual
926922	58	4	62	1.7	42	2	44	0.7	108.62	15.32	123.94	79.94	Actual
926924	52	4	56	1.6	40		40	0.8	126.46	18.06	144.52	104.52	Actual
367900	52	3	55	1.5	50	2	52	1.0	239.6	4.47	244.07	192.07	Estimated per 36 months - effective 200201
367902	56	1	57	1.6	52	3	55	0.9	240.3	0.53	240.83	185.83	Estimated per 36 months - effective 200201
750279	51	7	58	1.6	51	11	62	1.0	568.8	15.3	584.1	522.1	Estimated per 18 months - effective 200304
749675	51	8	59	1.6	51	2	53	1.0	568.8	9.85	578.65	525.65	Estimated per 18 months - effective 200304
749676	51	8	59	1.6	51	7	58	1.0	568.8	21.95	590.75	532.75	Estimated per 18 months - effective 200304
756647	51.6	7	58.6	1.6	51.6	4	55.6	1.0	568.8	12.08	580.88	525.28	Estimated per 18 months - effective 200304
756108	51.6	4	55.6	1.5	51.6	1	52.6	1.0	568.8	4.8	573.6	521	Estimated per 18 months - effective 200304
756646	51.6	10	61.6	1.7	51.6	3	54.6	1.0	568.8	48.45	617.25	562.65	Estimated per 18 months - effective 200304
760785	60		60	1.7	48		48	0.8	139.6		139.6	91.6	Estimated per 18 months - effective 199801
760685	60		60	1.7	48		48	0.8	166.6		166.6	118.6	Estimated per 18 months - effective 199801
765968	60		60	1.7	48		48	0.8	139.6		139.6	91.6	Estimated per 18 months - effective 199801
765935	60		60	1.7	48		48	0.8	166.6		166.6	118.6	Estimated per 18 months - effective 199801
814319	58	1	59	1.6	48	1	49	0.8	148.94		148.94	99.94	Estimated per 18 months - effective 199701
820522	52	2	54	1.5	48	2	50	0.9	155.9		155.9	105.9	Estimated per 18 months - effective 199701
830214	56	1	57	1.6	48	1	49	0.9	184		184	135	Estimated per 18 months - effective 199701
865592	43		43	1.2	43		43	1.0	193.42		193.42	150.42	Starts appear to be underestimated. Changed to be consistent with load run

EDG Success Data

DeviceID	Test Start Demands	Operation Start Demands	Total Start Demands	Avg Starts / Month	Test Load Demands	Operation Load Demands	Total Load Demands	Avg Load Run / Start	Test Run Hours	Operation Run Hours	Total Run Hours	Run - Load Run Hours	Comments
865593	50		50	1.4	50		50	1.0	215.78		215.78	165.78	Starts appear to be underestimated. Changed to be consistent with load run
865544	50		50	1.4	50		50	1.0	199.72		199.72	149.72	Starts appear to be underestimated. Changed to be consistent with load run
865545	45		45	1.3	45		45	1.0	214.34		214.34	169.34	Starts appear to be underestimated. Changed to be consistent with load run
865594	61		61	1.7	61		61	1.0	256.08		256.08	195.08	Starts appear to be underestimated. Changed to be consistent with load run
868007	39	1	40	1.1	84	1	85	2.2	39	2.5	41.5	-43.5	Estimated per 24 months - 199911
868008	39	1	40	1.1	84	1	85	2.2	39	1.13	40.13	-44.87	Estimated per 24 months - 199911
871940	36	13	49	1.4	36		36	1.0	54	16	70	34	Estimated per 18 months - 199801
871775	36	10	46	1.3	36		36	1.0	54	7	61	25	Estimated per 18 months - 199801
875868	36	7	43	1.2	36		36	1.0	54	9.4	63.4	27.4	Estimated per 18 months - 199801
875869	36	17	53	1.5	36		36	1.0	54	8.6	62.6	26.6	Estimated per 18 months - 199801
769866	72		72	2.0	52		52	0.7	116.6		116.6	64.6	Estimated per 36 months - effective 200201
769940	52		52	1.4	46		46	0.9	112.4		112.4	66.4	Estimated per 36 months - effective 200201
878576	43		43	1.2	45		45	1.0	137.07		137.07	92.07	Start Demands estimated per 36 months - effective 200201. Other failure modes actual data
878423	58		58	1.6	44		44	0.8	132.1		132.1	88.1	Start Demands estimated per 36 months - effective 200201. Other failure modes actual data
883291	56		56	1.6	56		56	1.0	177.9		177.9	121.9	No data recorded for 1999 - 2001. Used 200301 - 200512,
882490	53		53	1.5	53		53	1.0	172.9		172.9	119.9	No data recorded for 1999 - 2001. Used 200301 - 200512,
887650	52		52	1.4	47		47	0.9	143.2		143.2	96.2	No data recorded for 1999 - 2001. Used 200301 - 200512,
887652	51		51	1.4	49		49	1.0	137.1		137.1	88.1	No data recorded for 1999 - 2001. Used 200301 - 200512,
892650	60		60	1.7	40		40	0.7	327.94	3.5	331.44	291.44	Actual
892685	55		55	1.5	42		42	0.8	307.06		307.06	265.06	Actual
898018	48		48	1.3	43.5		43.5	0.9	117		117	73.5	Estimated per 24 months - effective 200304
898020	48		48	1.3	43.5		43.5	0.9	117		117	73.5	Estimated per 24 months - effective 200304
898886	46.5		46.5	1.3	43.5		43.5	0.9	117		117	73.5	Estimated per 24 months - effective 200304
898885	46.5	1	47.5	1.3	43.5	1	44.5	0.9	117	8.57	125.57	81.07	Estimated per 24 months - effective 200304
903501	70		70	1.9	53		53	0.8	110.9		110.9	57.9	Actual
903397	58		58	1.6	46		46	0.8	121.8		121.8	75.8	Actual
TOTAL	**12977**	**795**	**13772**	**1.7**	**11319**	**525**	**11843**	**1.0**	**35607**	**2406**	**38013**	**26170**	
AVERAGE			**62**				**53**				**171**	**118**	Average per EDG for three years
FAILURES			**75**				**42**				**20**	**20**	
FAILURES			**75**				**42**				**18**	**18**	
Table 8 RATE			**5.00E-03**				**3.00E-03**				**8.00E-04**	**8.00E-04**	
MLE RATE			**5.45E-03**				**3.55E-03**				**5.26E-04**	**7.64E-04**	
MLE RATE			**5.45E-03**				**3.55E-03**				**4.74E-04**	**6.88E-04**	

https://allthingsnuclear.org/dlochbaum/nuclear-powerless-plants/

allthingsnuclear.org

Nuclear Power(less) Plants

Dave Lochbaum Former contributor
18-23 minutes

Disaster by Design/Safety by Intent #3

Disaster by Design

The primary purpose of commercial nuclear power plants in the U.S. is to generate electricity. When not fulfilling that role, nuclear power plants that are shut down require electricity to run the equipment needed to prevent the irradiated fuel in the reactor core and spent fuel pool from damage by overheating. The March 2011 accident at Fukushima Daiichi in Japan graphically illustrated what can happen when nuclear plants do not get the electricity they require.

U.S. nuclear power plants are designed with three sources of electricity: (1) the offsite power grid, (2) the backup power supply, and (3) the direct current power from batteries. (The responses to the 9/11 and Fukushima tragedies added a fourth source in the form of portable generators, but the reliability is significantly lower because this equipment is not purchased, tested, and maintained to anything close to the high standards applied to the other sources.)

When electricity from the offsite power grid is available, a nuclear plant has the largest inventory of cooling equipment available. When the offsite power grid is not available, the backup power supply has sufficient capacity for the emergency equipment, but not for the normal cooling equipment. And when the offsite power grid and the backup power supply are both unavailable—plunging the plant into what is called a station blackout—the batteries have sufficient capacity for a single cooling system for a handful of hours.

Offsite Power Grid Problems

The NRC examined times when U.S. nuclear power plants were disconnected from their offsite power grids. The NRC's term for such events is Loss of Offsite Power (LOOP). The NRC reported roughly the same number of LOOP events when plants were operating (55) as when plants were shut down (58), even though nuclear plants tend to spend more time operating than shut down. The NRC identified four causes for LOOP events: (1) plant-centered, (2) switchyard-centered, (3) grid-related, and (4) weather-related. The relative number of each cause are shown in Fig. 1

Table 1. Plant-level LOOP frequencies.

Mode	LOOP Category	Data Period	Events	Reactor Critical or Shutdown Years	Maximum Likelihood Estimator	Frequency Units[a]
Critical Operation	Plant-centered	1997–2013	3	1567.9	1.91E−03	/rcry
	Switchyard-centered	1997–2013	22	1567.9	1.40E−02	/rcry
	Grid-related	1997–2013	18	1567.9	1.15E−02	/rcry
	Weather-related	1986–2013	12	2445.3	4.91E−03	/rcry
	All[b]		55	1701.7	3.23E−02	/rcry
Shutdown Operation	Plant-centered	1986–2013	23	471.6	4.88E−02	/rsy
	Switchyard-centered	1997–2013	13	192.2	6.76E−02	/rsy
	Grid-related	1986–2013	5	471.6	1.06E−02	/rsy
	Weather-related	1986–2013	17	471.6	3.60E−02	/rsy
	All[b]		58	355.8	1.63E−01	/rsy

a. The frequency units are per reactor critical year (/rcry) or per reactor shutdown year (/rsy).

b. In the "All" rows, the events and rate estimators are summed across LOOP categories. The years are calculated so that the counts divided by the years equal the rates.

Fig. 1 (Source: NRC)

Plant-Centered LOOPs

An event on March 25, 2003, at the Palisades nuclear plant in Michigan is indicative of a plant-centered LOOP; although like snowflakes, no two are alike. The plant was shut down at the time for refueling. Workers installing a post for a sign in the plant's parking lot penetrated through an underground conduit containing electrical cables. (The reports didn't say what the sign read. Hopefully, the sign did not say "CAUTION: Important Cables Buried Below" or "No Digging.") The control circuits for both of the offsite power transmission lines were damaged, causing a LOOP. The emergency diesel generators—the backup power supply—automatically started. But the low pressure safety injection pump that had been running to cool the reactor core was not automatically connected to the buses supplied by the emergency diesel generators. It took the operators 20 minutes to restore reactor core cooling.

Switchyard-Centered LOOPs

An event on March 20, 1990, at the Vogtle nuclear plant in Georgia illustrates a switchyard-centered LOOP. The unit was shut down at the time for refueling. A worker drove a fuel truck into the switchyard to refill the tank of a welding machine. Trying to turn around and exit the switchyard, the worker backed the truck into a pole supporting the 230,000 volt overhead transmission line. The impact caused an electrical fault that de-energized the in-service transformer between the grid and the unit, triggering a LOOP. One of the two emergency diesel generators was out of service for maintenance. The remaining emergency diesel generator automatically started. But a sensor on its cooling system malfunctioned and stopped the emergency diesel generator. The sensor had malfunctioned 69 times since 1985, or roughly once a month, but had never been fixed or replaced. The unit was in a station blackout. The temperature of the reactor cooling water rose from 90°F to 136°F in the 36 minutes it took for workers to restart the emergency diesel generator in emergency mode (bypassing the cooling water sensor problem) and restore reactor core cooling.

Grid-Related LOOPs

An event on June 14, 2004, at the Palo Verde nuclear plant in Arizona illustrates a grid-related LOOP. All three reactors were operating when an electrical fault occurred on a 230,000 volt transmission line about 47 miles from the plant. A circuit intended to isolate the electric disturbance failed, allowing a ripple effect across the power grid. All three reactors at Palo Verde automatically shut down due to the fluctuating conditions on the power grid and six non-nuclear generating units on the grid also shut down. All the emergency diesel generators at Palo Verde automatically started, except for one of two emergency diesel generators for Unit 2. A diode in a control circuit failed, disabling the emergency diesel generator. The plant's response to the triple shut down was complicated by:

- the emergency diesel generator for the Technical Support Center not working due to a mis-positioned switch,
- lack of understanding about a temporary modification on Unit 1 that allowed the letdown system to cause excessively high temperature in a downstream system that ignited paint on the overheated piping,
- a leaking check valve in the Unit 3 safety injection system that forced the operators to manually depressurized the low pressure safety injection system three times to protect its piping from becoming over-pressurized,
- and failure of two electrical circuit breakers to operate that delayed workers in restoring power to plant equipment.

Despite these, and other, problems, the operators were able to safely shut down all three reactors.

Another grid-related event on August 14, 2003, in the northeastern U.S. and parts of Canada caused eight operating U.S. reactors (Fermi Unit 2 in Michigan; Perry in Ohio; and FitzPatrick, Indian Point Units 2 and 3, Nine Mile Point Units 1 and 2, and Ginna in New York) to experience LOOPs. Offsite power was restored to Ginna in 49 minutes. It took 6 hours and 24 minutes to restore offsite power at Nine Mile Point Unit 2. While some plants experienced equipment malfunctions that complicated the response to the LOOP, all endured it successfully and restarted shortly afterward.

Appendix A to a report released by the NRC in December 2003 summarizes 83 grid events between 1994 and 2001 that affected U.S. nuclear power plants. The compilation included the December 14, 1994, event where a transmission line fault in Idaho rippled across the western U.S., affecting Diablo Canyon Units 1 and 2 and San Onofre Unit 2 in California; Palo Verde Units 1 and 2 in Arizona; and Columbia Generating Station in Washington.

Weather-Related LOOPs

The damage inflicted on August 24, 1992, as Hurricane Andrew hit south Florida, including the Turkey Point nuclear plant, is an example of a weather-related LOOP. Both reactors had been shut down as a precautionary measure before the hurricane's arrival. The hurricane downed transmission lines, causing a LOOP at Turkey Point that lasted nearly five days. The high winds also damaged onsite antennas and offsite repeating stations. The plant was without telephone or radio communications for four hours, except for one hand-held radio. The fire protection system was impaired when high winds blew a tower onto the 500,000 gallon storage tank. Both reactors endured the challenge and were restarted days later.

The NRC examined four hurricanes that visited the southeastern U.S. during 2004 for the consequences at Brunswick Units 1 and 2 in North Carolina and St. Lucie Units 1 and 2 and Crystal River 3 in Florida.

- Hurricane Charley caused an offsite transmission line fault that triggered the automatic shut down of Brunswick Unit 1. The power outage disabled 25 of the 36 emergency sirens within the emergency planning zone.

- Operators began manually shutting down both reactors at St. Lucie on September 3, 2004, as Hurricane Frances approached. During the storm, the Emergency Response Data Acquisition Display System link to NRC headquarters as well as the Emergency Notification System direct connection between the plant and NRC headquarters was lost for hours.

- Operators began shutting down both reactors at St. Lucie again on September 25, 2004, as Hurricane Jeanne approached. This time, the Emergency Response Data System connection between the plant and the NRC's Incident Response Center was lost. After the storm passed, workers discovered that the exterior doors on the east side of the Unit 2 reactor auxiliary building were wide open. The plant's safety studies assumed these doors were closed during reactor operation and severe weather to act as missile shields, protecting vital equipment inside from debris picked up and propelled by high winds. The doors had been left open during Hurricane Jeanne due to "lack of procedural guidance."

- Crystal River 3 automatically shut down on September 6, 2004, when Hurricane Frances' high winds caused a phase-to-ground fault in the 230,000 volt switchyard. The fault was attributed to "diameter loss and subsequent mechanical failure of a carbon steel pin in a vertical slice of insulators" with the diameter loss "caused by possible leakage current, which led to spark erosion and severe electrochemical corrosion of the carbon steel pin"—Nukespeak for the thing done getting fried by high voltage current.

Backup Power Supply Problems

LOOPs mean the normal, preferred source of electricity to a nuclear power plant is unavailable. Emergency diesel generators, with the sole exception of hydroelectric generating units for the Oconee nuclear plant in South Carolina, are the backup power supply for U.S. nuclear power plants. Essentially locomotive diesel engines without the wheels and whistle, emergency diesel generators can supply power to emergency equipment designed to mitigate transients (like LOOPs) and accidents (like loss of coolant accidents) and protect workers and the public.

Emergency diesel generators are highly reliable, but far from infallible. A report issued for the NRC in 2011 on emergency diesel generator failures a decade earlier noted 137 emergency diesel generator failures during the three-year period 1999-2001 across the fleet of nearly 100 U.S. nuclear power reactors (Fig. 2). The failures included times when an emergency diesel generator failed to successfully start, times when it started but failed to connect to its electrical distribution bus (also termed failing to supply electricity to the equipment loaded on the bus), and times when it started and supplied its loads only to later fail while running. The apparent high number of failures is tempered by the large number of tests: there were 75 times among 13,772 demands (combination of tests and responses to actual events) when an emergency diesel generator failed to start, 42 times among 11,843 demands where an emergency diesel generator failed to supply its loads, and 20 times during 26,170 hours of run-time when an emergency diesel stopped running unintentionally.

Type	Total	Start	Load Run	Run
Number of Failures	137	75	42	20
Success Data		13,772 demands	11,843 demands	26,170 hours
Average (Demands/Hours) per EDG per year		62 demands	53 demands	118 hours
Maximum Likelihood Failure Rate		5.45E-03	3.55E-03	7.64E-04

Fig. 2 (Source: Table 3 from NRC) (EDG = Emergency Diesel Generator)

Some of the more recent emergency diesel engine failures include:

- **Arkansas Nuclear One (Arkansas)**: The Unit 2 emergency diesel generator 4A caught on fire about one minute after being started for a monthly test run on August 3, 2007. Workers determined that a warped panel used to cover an inspection port allowed oil to leak onto the exhaust header.

- **Calvert Cliffs (Maryland)**: The Unit 1 emergency diesel generator B caught on fire 1 hour and 20 minutes into a monthly test run on August 12, 2007. Lubricating oil leaked from several loose bolts connecting the engine top cover to the exhaust manifold and ignited. The ensuing investigation found that 15 of the 122 bolts were at less than the 40 to 55 foot-pounds torque value specified by the vendor to ensure proper bolt tightness. The procedure used at the plant did not specify a torque value for the engine top cover bolts.

- **Fermi Unit 2 (Michigan)**: Emergency diesel generators 11 caught on fire during a post-maintenance test run on January 31, 2003. Fuel oil spilled from the clean fuel drain header vent onto the injector deck where it flowed onto the exhaust manifold and ignited. Two weeks earlier, workers installed temporary plastic sleeves on the drain lines from the clean fuel drain header without following approved modification procedures. The plastic sleeves restricted flow through the drain lines, allowing fuel oil to back up and overflow from the vent header.

- **North Anna (Virginia)**: The Unit 2 emergency diesel generator H caught on fire during a test run in September 2006. Workers determined that lubricating oil had leaked past bolts onto the exhaust manifold. The bolts had been replaced during maintenance in the spring of 2006 and the replacement bolts were longer than the original bolts, creating a pathway for oil leakage.

- **Palo Verde (Arizona)**: The Unit 2 emergency diesel generator A unexpectedly stopped running during a monthly test on November 12, 2008. Troubleshooting identified damage to the excitation control system for the generator. An offsite laboratory examined the damaged parts and determined that misalignment of parts during assembly at the manufacturer created a sharp edge. When the emergency diesel generator ran, its vibrations allowed the sharp edge to slowly cut through the insulation on control wires, allowing an electrical fault.

- **Peach Bottom (Pennsylvania)**: The Unit 2 emergency diesel generator E2 caught on fire during a test run on April 19, 2003. Loose bolts holding the engine top cover in place allowed lubricating oil to leak onto the exhaust manifold. Maintenance procedures did not specify the torque value recommended by the vendor to ensure proper tightness, but instead directed workers to tighten the bolts until they were “wrench-tight.”

- **San Onofre Unit 3 (California)**: Emergency diesel generator A failed to start during a test on December 12, 2009. Workers found that a capacitor failure in the power supply for the local alarm panel allowed an electrical transient that affected the speed switch circuit and prevented the emergency diesel generator from being started.

The causes of these failures include manufacturing problems, inadequate maintenance practices, and improper modifications.

Direct Current from Batteries Problems

Should a nuclear plant become deprived of both the electricity from the offsite power grid and from the backup power supply, it experiences a station blackout where the only remaining source of electricity is direct current from onsite batteries. The batteries are normally kept fully charged from the alternating current systems through inverters and chargers. The station batteries are designed to supply sufficient electricity to a minimal subset of emergency equipment needed to cool the reactor core for 4 to 8 hours when it is assumed that either the connection to the offsite power grid will be restored or at least one of the backup power supplies will be repaired and returned to service.

Fig. 3 (Source: Tennessee Valley Authority)

Some recent problems involving station batteries include:

- **Davis-Besse (Ohio)**: On July 26, 2001, NRC inspectors identified that the electrical cables and associated relays for non-essential loads on the station batteries were not qualified for the post-accident environment they would experience. Specifically, the direct current supplies to the backup oil lift pump motors for the four reactor coolant pumps and to the containment lighting panel could fail following an accident. Their failure could shorten the life of the station batteries to less than assumed in the plant's safety studies.

- **Indian Point Unit 3 (New York)**: During a weekly surveillance test, workers discovered a crack in the casing for cell 14 of station battery 33 on October 9, 2013. The crack extended below the high level fluid level of the cell. The damaged cell was replaced. Workers attributed the crack to corrosion on the positive battery post which caused the post to expand and put excessive stress on the casing.

- **San Onofre Unit 2 (California)**: Workers conducting a weekly surveillance test identified an apparent low-voltage condition on one of the four banks of station batteries on March 25, 2008. The problem was attributed to loose bolts on the connection for the charging cable dating back to a maintenance task performed on March 17, 2004.

- **Waterford (Louisiana)**: Workers found that the capacity of station battery B was 86.25% of the manufacturer's rating during a test on May 16, 2008. Although this result satisfied the regulatory requirement of at least 80% rated capacity, it was significantly below the average value of 103.7% recorded during prior tests. Workers conducted a follow-up test on May 22, 2008, and found the capacity had dropped to 71.67%. The batteries were replaced. Because the battery cells were thrown away, no root cause of the problem could be established. The batteries had a rated service life of 20 years but failed after 15.6 years.

- **Waterford (Louisiana)**: In the midst of Hurricane Gustav, the operators declared station battery 3B-D inoperable due to low voltage on September 3, 2008. Workers determined the problem to be loose bolts on the connection between battery cells 57 and 58. The bolts had been loosened on May 29, 2008, when cell 56 was replaced and apparently had not been properly retightened.

The causes of these failures include design problems, inadequate maintenance practices, and aging degradation.

Safety by Intent

Nuclear power plants are designed with three sources of electricity for emergency systems needed to protect reactor cores from overheating damage. Because each source is highly reliable, it's unlikely that all three will fail when needed. But all three failed at Fukushima, and all three could fail again.

Look at the math. For illustration, assume that each source is 95% reliable, meaning each source has a 5% (expressed as 0.05) chance of failure. The chance that all three sources fail is therefore 0.05 times 0.05 times 0.05 or 0.000125 => .0125% or 1.25 triple failures in 10,000 trials.

What happens when design errors, inadequate maintenance practices, and/or aging degradation reduce the reliability of the sources?

Suppose that the reliability of each source drops to 90%. Something succeeding 9 times out of 10 seems pretty safe, especially considering that three 90% reliable sources must concurrently fail to cause real harm. The chance of all three 90% reliable sources fail is 0.1 times 0.1 times 0.1 or 0.001 => 0.1% or 1 triple failure in 1,000 trials.

Safety is enhanced when impairments are flushed out and fixed because the reliability of protective barriers increases.
Safety is degraded when impairments remain hidden or remain uncorrected because the reliability of protective barriers decreases.

UCS's Disaster by Design/Safety by Intent series of blog posts is intended to help readers understand how a seemingly unrelated assortment of minor problems can coalesce to cause disaster and how addressing pre-existing problems can lead to a more effective defense-in-depth protection.

ELECTROMAGNETIC DEFENSE TASK FORCE 2.0

2019 REPORT

Maj David Stuckenberg
Amb. R. James Woolsey
Col Douglas DeMaio

Edited by
Donna Budjenska

LEMAY PAPERS

AIR UNIVERSITY

LEMAY CENTER FOR DOCTRINE DEVELOPMENT AND EDUCATION

ELECTROMAGNETIC DEFENSE TASK FORCE (EDTF) 2.0

2019 REPORT

Maj David Stuckenberg
Amb. R. James Woolsey
Col Douglas DeMaio

Edited by
Donna Budjenska

LeMay Paper No. 4

Air University Press
Maxwell Air Force Base, Alabama

Commander, Curtis E. LeMay Center for Doctrine Development and Education
Maj Gen Brad M. Sullivan

Contributing Editors
Maj Jeremiah Gilmore
Mr. Dwayne Florence
Maj Stacy Rankin
Maj Rachel Ramirez

AIR UNIVERSITY PRESS

Director, Air University Press
Lt Col Darin Gregg

Managing Editor
Dr. Christopher Rein

Project Editor
Donna Budjenska

Cover Art, Book Design, and Illustrations
Leslie Susan Fair

Composition and Prepress Production
Nedra O. Looney

Print Preparation and Distribution
Diane Clark

Air University Press

600 Chennault Circle, Building 1405
Maxwell AFB, AL 36112-6010
https://www.airuniversity.af.edu/AUPress

Facebook:
https://www.facebook.com/AirUnivPress
and
Twitter: https://twitter.com/aupress

Published by Air University Press in August 2019

Disclaimer

AIR UNIVERSITY PRESS

To obtain additional copies of this report or for additional information on the EDTF, contact Air Education Services at (800) 262-9140 or email au.education.support@us.af.mil.

ELECTROMAGNETIC DEFENSE TASK FORCE (EDTF)

2019 REPORT

Approved for Public Release

This conference report is a product of the United States Air Force Education and Training Command, Air University and the Curtis E. LeMay Center for Doctrine Development and Education

Contents

Foreword

In every region of the globe, every day, the defense community works to ensure the health and security of the United States, our allies, and our interests.

The Electromagnetic Defense Task Force (EDTF), now in its second year, has provided great leadership and utility to the defense ecosystem by linking diverse experts and professionals together to make candid holistic assessments of threats emerging from within the electromagnetic spectrum. By forming a coalition of professionals without silos, the EDTF has discovered fresh insights that deserve deep consideration and perhaps bold action.

It is my hope you will continue to support and enhance this effort, and others like it, as we look over the horizon toward the threats ahead.

Lieutenant General Steven L. Kwast
Commander, Air Education and Training Command

Executive Summary

In 2018, the Electromagnetic Defense Task Force (EDTF) was created to undertake an audacious effort to holistically understand challenges and opportunities facing militaries and societies in an age increasingly dominated by the electromagnetic spectrum (EMS), a broad area of activity characterized by the visible and invisible movement of light and energy. The task force was a triage response to an enterprise-wide knowledge deficiency about the criticality of issues confronting the United States and its allies as every aspect of modern society becomes increasingly reliant on the EMS.

As the journey began, the principals assembled a coalition of experts ("fellows") like no other, including a broad and diverse range of representatives from every possible agency, including federal, military, industry, and academia. The effort also required a unique approach to addressing complex and even seemingly unsolvable challenges. To accomplish this, fellows took part in almost 5,000 hours of war-gaming and tabletop exercises (TTX) to develop a more comprehensive understanding of the central issues within the community.

The EDTF ecosystem now comprises more than 360 distinguished fellows, many of whom have invested the greater part of their careers solving and understanding the intricacies of the EMS. Covering EMS management and 5G to electromagnetic pulse (EMP) and space weather to quantum and lasers to directed energy and beyond, the task force's primary purpose is to digest and disseminate EMS knowledge of a critical nature to the defense community. Thus, in 2018, the EDTF published four key findings:

- **Finding 1:** EMP and geomagnetic disturbance (GMD) are significant and continuing threats to the military and civil society. Risks include but are not limited to nuclear power station resilience, military installation resilience, and exercise realism and training (education).
- **Finding 2:** Emerging 5G technologies and the design of regional and continental networks can present strategic threats.
- **Finding 3:** Directed energy (DE) and high-powered microwave systems can pose threats to human biology and hardware dependent on electronics.
- **Finding 4:** EMS management is struggling to maintain pace with rapid technical evolutions within the spectrum.

Furthermore, it was understood that the EMS had unique characteristics deserving priority consideration. EMS had become an essential part of every war-fighting domain (space, air, land, sea, and cyberspace)—yet was often poorly understood due to a lack of education—and it was maturing as form of gray zone warfare (competition below the threshold of war) used by revisionist powers to challenge the "rules-based order."[1]

In short, the EMS was a powerful area of activity ready for tactical-, operational-, and strategic-level exploitation. Finally, as the task force evaluated the complexities of how modern societies function, it became apparent that along with cyber, the most unique and effective way to affect large segments of a modern nation without a retaliatory attack was to use the EMS to disrupt life-sustaining elements such as water, food, sanitation, communications, transportation, and—especially—the electric power infrastructure upon which all such systems depend. Based on extensive war gaming, the task force also found that certain EMS phenomena may potentially bypass traditional strategic deterrence schemes and present challenges to the health and economies of states, even up to the point of "stop[ping] a modern nation's broad civil and defense activities."[2]

To address these findings, the 2018 EDTF report made a series of national-, regional-, and local-level recommendations on how to increase the resilience of key military and civil critical infrastructure. The report remains one of the most accessed documents in the history of Air University and has been discussed by media around the world. In 2018, two of the task force's findings were addressed by presidential executive orders. The third finding supported Headquarters US Air Force actions. However, the work required to lend advantage to the United States and its allies, in what may prove to be one of the most technologically important areas in the history of competition, is far from complete.

In 2019, the Vice Chairman of the Joint Chiefs of Staff (VCJCS) met with EDTF leaders and noted the value of the task force to the international dis-

---

1. The rules-based order is often described as the international *status quo* (or way things are) while revisionist powers are those whose efforts seek to upset the international order. Chatham House, The Royal Institute of International Affairs. The London Conference: Challenges to the Rules-Based International Order. London, UK: Chatham House, 2015, https://www.chathamhouse.org/london-conference-2015/background-papers/challenges-to-rules-based-international-order. The text reads: "The international order established by the victorious allies after the Second World War has been remarkably enduring. The framework of liberal political and economic rules, embodied in a network of international organizations and regulations, and shaped and enforced by the most powerful nations, both fixed the problems that had caused the war and proved resilient enough to guide the world into an entirely new era. But given its antique origins, it is not surprising that this order now seems increasingly under pressure. Challenges are coming from rising or revanchist states; from unhappy and distrustful electorates; from rapid and widespread technological change; and indeed from the economic and fiscal turmoil generated by the liberal international economic order itself."

2. David Stuckenberg, R. James Woolsey, and Douglas DeMaio, "Significant Findings," in *Electromagnetic Defense Task Force 2018 Report* (Maxwell AFB, AL: Air University Press): 7–8, https://www.airuniversity.af.edu/Portals/10/AUPress/Papers/LP_0002_DeMaio_Electromagnetic_Defense_Task_Force.pdf.

course on the EMS. Furthermore, the VCJCS evaluated and concurred with a war-gaming scenario for use as a backdrop to answering four questions during the second summit:

1. **Based on the [EMS] scenario, assess post-event Joint Force (military) capabilities: what assets/functions remain viable?**
2. **Based on what remains viable (preserved): what Joint Force strategies/regeneration options can be realistically put forward to national leaders for recovery and/or military response?**
3. **What are our strategic blind spots in regard to each track in a severe EMS-degraded environment, and how should we place near-term bets to counter/frustrate enemy efforts?**
4. **What happens when we lose position, navigation, and timing (PNT)?**[3]

During the second summit held 29 April–1 May 2019, more than 220 fellows participated in a series of TTXs (or war games) organized into four tracks: (1) electromagnetic spectrum operations (EMSO), (2) high-powered electronics and microwaves (HPEM)/DE/spectrum management, (3) EMP and GMD, and (4) quantum and 5G technologies. In total, 17 teams formed, including two special teams to address nuclear power station vulnerabilities and analyze commercial reports and data generated by the electric power industry.

This report makes no claim about the consensus of the more than 100 military, civil, academic, and corporate employers represented or the task force's sponsors, Air University and Headquarters Air Force EMS Enterprise Capability Collaboration Team (EMS/ECCT). The narrative of this report should be considered the opinions of the primary authors based on an in-depth assessment of the totality of information covered and more than 4,800 hours of war gaming and study conducted by and with the task force's fellows. A classified briefing to this report is available on request to approved individuals and organizations.

EDTF 3.0 will be held in the National Capital Region in late 2019 or early 2020. The task force would like to recognize the efforts of more than 360 fellows who continue to contribute to this body of work. Thank you!

3. PNT is roughly equivalent to the functions provided by the modern US Global Positioning System (GPS) satellite constellation.

Introduction

We live in a time like no other in history. Things once thought impossible—such as the ability to travel by air and through space, the capability to sense or detect objects at great distances and see through dense materials, and the power to effortlessly communicate and move information across the universe—are now a part of the daily normal in much of the world. All of these advancements are underpinned by the electromagnetic spectrum (EMS), and each has become increasingly integral to the functionality and sustainment of modern civilizations.

The United States and its allies have an opportunity to either rapidly seize the initiative or watch competitors exploit these conditions at our expense.

However, it is also a time when the rules of the current global order are being called into question and rewritten. This transformation is driven in part by the reemergence of a great power struggle, the democratization of capability and knowledge, and a convergence of novel technologies.[1] Where these conditions intersect with the EMS, warfare, operations, the gray zone, and conventional defense elements, the United States and its allies have an opportunity to either rapidly seize the initiative or watch competitors exploit these conditions at our expense. Seizing the opportunity and preventing adversary exploitation will require a willingness to embrace thinking freed from past paradigms.

Primacy of learning, or how something is first learned, is a powerful influence on how humans think and behave.[2] In short, primacy establishes early cognitive patterns and habits of mind–the first wiring of our brain and how we tend to instinctively think and act.[3] When demonstrated in warfare, such thought patterns have led to unimaginable outcomes.

The largest defeat of a modern army by an indigenous force was suffered by the British at Islandlwana on 22 January 1879 (in the opening volley of the Anglo-Zulu war). Armed with short spears and cowhide shields, an army of 20,000 Zulu overtook 2,200 British regulars armed with breach-loading rifles and cannon. One day after this tragedy, 139 engineers at Rorke's Drift, a

1. David Stuckenberg, "Deterrence in the Gray Zone: Understanding NATO's Strategic Sufficiency" (unpublished PhD diss., King's College London, 2019), 7–10.

2. Vernon A. Stone, "A Primacy Effect in Decision-Making by Jurors," *Journal of Communication* 19, no. 3 (September 1969): 239–47, https://doi.org/10.1111/j.1460-2466.1969.tb00846.x.

3. Stone, "A Primacy Effect," 53.

missionary outpost converted to field hospital, successfully fended off an attack by 4,000–7,000 Zulu. In this instance, British losses were limited to just 17 while the Zulu army suffered more than 2,000. The troop numbers and technologies used in both battles were proportionally equivalent. But the outcomes of these battles demonstrate that thinking—in contrast to technology—can be the differentiating element between life and death, victory and defeat.

At the Battle of Islandlwana, a seasoned commander, Lt Gen Frederick Augustus Thesiger, allegedly ignored information and intelligence about Zulu strategy, while the young officers at Rorke's Drift, Lt John Chard and Lt Gonville Bromhead, leveraged these insights to adapt their strategy and technology to the environment. Against the backdrop of this and similar clashes, it can be said that primacy of learning is possibly the most accidently dangerous cognitive phenomenon to manifest itself in the history of warfare.[4] Primacy compels action(s) based on yesterday's ideas even if there is an intuitive understanding that such actions are destined to fail. Ironically, primacy may often endanger the most educated while advantaging the agile and even ignorant as they innovate free of tradition and thought-confining inhibitions.[5] The latter example can be thought of as "thinking to win."[6]

Sound examples of thinking to win are demonstrated again and again throughout history. From the American Revolution that used often irregular tactics against predictable British columns to the Industrial Revolution that introduced technology that would change the lives of millions, thinking to win and the use of actual environmental conditions are often decisive factors in conflict and competition that can influence the fates of nations. Thus this

4. Stone, "A Primacy Effect." This assertion is based on the broader evaluation of battles lost and casualties caused by use of outmoded warfare in the face of better designed strategies and disregarded intelligence. Another historic example was well demonstrated in Germany's use of tanks and radios under air cover to bypass French fortifications known as the Maginot Line (situated on the eastern French border with Germany). In this situation, France believed the fortifications would buy time during a German invasion and even deter invasion. However, France failed to anticipate Belgium would declare itself neutral and that Hitler's Panzer divisions would punch through the Maginot in areas characterized by forested rolling terrain. Finally, France began to believe in its own propaganda—chiefly that the Maginot Line was impenetrable. Such a belief diverted French attention from strategies that would rapidly bring troop reinforcements to the front near the Maginot.

5. Stone, "A Primacy Effect," 154–55.

6. Howard Wheeldon, "Thinking to Win—The RAF's New Leadership Strategy," Royal Aeronautical Society, accessed 1 June 2019, https://www.aerosociety.com/news/thinking-to-win-the-rafs-new-leadership-strategy/. "Thinking to win" is not a formal definition but a broad carrier idea that encapsulates mental agility, adaptivity, intelligence, innovation, determination, and a host of other cognitive habits that enable someone to outwit, outsmart, and win against the competition. This term has been used in literature in various forms. A recent use of the term was published by the Royal Aeronautical Society, as attributed to Air Chief Marshal Sir Andrew Pulford, at a lecture given at the Defence and Security Equipment International event, London, September 2015.

report is presented, first and foremost, with an understanding that technology in conflict and competition is important, but uninhibited and intellectually honest strategic thinking is paramount.

Irrespective of operation, whether on the ground, at sea, in the air, in space, or within cyberspace, communities of thinking warriors have always been dominant. Today is no different. As our nation prepares for what lies ahead, we must think to win!

Thinking to win makes unapologetic and unbiased appraisals of not only the environment but also competitor thinking and dispositions as well. This is done in order to develop a holistic understanding that enables those working within the environment to make rapid, informed, and intelligent judgments. Such thinking is not accidental but rather intentionally developed.

During a wider appraisal of the defense community, the presence of this kind of thinking with respect to the electromagnetic spectrum has been astonishingly absent. Primacy of learning for nearly all Americans—spanning civil servants and private citizens and including our most experienced war fighters—has a built-in assumption that many of these elements will be unchallenged.

However, in 2018 the White House, US Congress, the Enterprise Capability Collaboration Team (ECCT), and Electromagnetic Defense Task Force (EDTF) simultaneously converged on the reality that the preponderance of military forces is ill prepared for an environment characterized by a degraded electromagnetic spectrum. Thus, in 2019, the EDTF shifted its focus to Joint Force resilience rather than the wider US infrastructure. Notwithstanding, the Joint Force and civil society are codependent on the same infrastructure. Thus, the primary questions explored and exercised by the task force in 2019 kept this critical element in view.

Unlike other domains that connect but can be segregated, or that terminate at definitive boundaries such as a shoreline between land and the sea or at the skyline between air and land, the EMS crosscuts all domains.

While there is little consensus on when or where an EMS degradation might occur, or even the extent of damage that may occur, there is consensus on the technical and scientific feasibility (whether natural or man-made) of the threats and risks. Natural EMS events may be produced by a coronal mass ejection (CME) from the sun interacting with Earth's magnetic field (in what is known as a geomagnetic disturbance [GMD]) or by intentional acts generating electromagnetic pulse (EMP), laser energy, microwaves, or even use of 5G systems to access and/or disrupt information networks. The potentially catastrophic effects of these types of natural or man-made EMS events are not science fiction but science fact and have been well studied and documented for nearly six decades. These risks must continue to be addressed in accordance with responsive US laws which state, for example, "It is the policy of the United States to prepare for the effects of EMP through targeted approaches that coordinate whole-of-government activities and encourage private-sector engagement."[7]

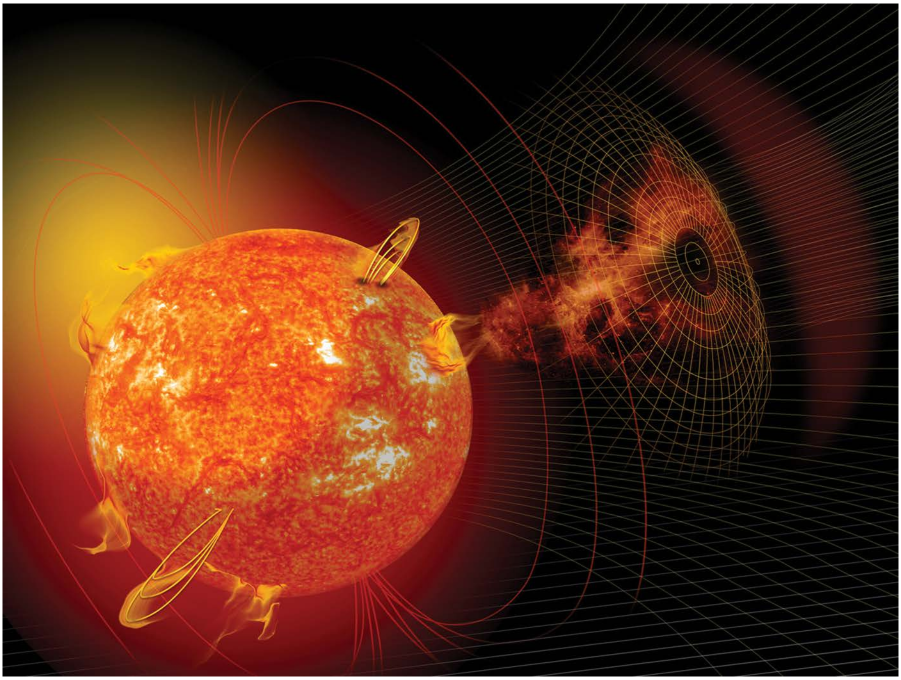


Figure 1. **Artist's depiction of a coronal mass ejection (CME)**. CMEs are magnetically generated solar phenomena that can send billions of tons of solar particles, or plasma, into space that can reach Earth one to three days later and affect electronic systems in satellites and on the ground. (Reproduced by permission from NASA.)

7. Executive Order (EO) 13865, Coordinating National Resilience to Electromagnetic Pulses, 26 March 2019, 3 C.F.R. 1, https://www.federalregister.gov/documents/2019/03/29/2019-06325/coordinating-national-resilience-to-electromagnetic-pulses. It is the policy of the United States to prepare for the effects of EMP though targeted approaches that coordinate whole-of-government activities and encourage private-sector engagement.

Given the life-sustaining umbilical between the Joint Force and civil society, it is reasonable that negative impacts to one side will bring negative impacts to the other. EMS effects may be evident regardless of whether shocks impact civil society, the military, or both and may, at times, be astonishing in scope.[8] In light of this, the EDTF advises that the strongest consideration be given to training the Joint Force in the foundational elements of how to operate and win in an EMS-degraded environment. This effort is already under way within the US Air Force and must be a national imperative not only within all military services but also within civil government. If education and training in this area are not made a priority, risk of total mission failure and loss of civil order cannot be dismissed. This is in part due to the exceptional and unique attributes of the EMS.

Unlike other domains that connect but can be segregated, or that terminate at definitive boundaries such as a shoreline between land and the sea or at the skyline between air and land, the EMS crosscuts all domains. In other words, degradation to an EMS environment can degrade operations in and permeate all other environments at the same time.

In this region of unbounded risk, current and future adversaries may attempt to achieve strategic offsets that simultaneously undermine operations in all domains. At the writing of this paper, quantum physics is advancing experimentation that allows for the instantaneous manipulation of physical properties across space and time. To date, the US and China have advanced quantum communications techniques that raise the specter of broadcast-free (with no antenna) global communications. As technologies advance, a significant EMS degradation may be potentially more devastating and ubiquitous than even large-scale and simultaneous cyberattacks.

The US faces almost impossible odds of winning future competitions if the EMS domain is insufficiently dominated by Western interests.

In understanding how to posture people and assets to counter EMS threats at all levels, it is well understood the United States has always oriented forces with respect to domains.[9] Notwithstanding, it bears consideration that the

8. John S. Foster Jr., Earl Gjelde, William R. Graham, Robert J. Hermann, Henry M. Kluepfel, Richard L. Lawson, Gordon K. Soper, Lowell L. Wood Jr., and Joan B. Woodard, *Report of the Commission to Assess the Threat to the United States from Electromagnetic Pulse (EMP) Attack*, Cong. Rept. 1-208, April 2008, https://apps.dtic.mil/dtic/tr/fulltext/u2/a484672.pdf.

9. Presently the accepted US Department of Defense war-fighting domains include air, land, sea, space, and cyberspace.

true power and potential of EMS was overlooked because our understanding of the broader environment developed piecemeal over time. Consequently, the Department of Defense (DOD) and other exponents tended to undertake disjointed and uncoordinated activities that failed to holistically address the totality of issues inherent to an exceptional, demanding, and complex environment. Thus, while in 2018 EDTF addressed the potential value in naming EMS a war-fighting domain, this 2019 report makes the strongest and most robust recommendation that EMS be declared a joint war-fighting domain.

While the concept of EMS as a domain may seem unnecessary and even adventurous, there remains virtually no other way to advantage the United States and its allies in this increasingly contested area of rapidly expanding operations. The US faces almost impossible odds of winning future competitions if the EMS domain is insufficiently dominated by Western interests. This exceptional domain cannot be isolated, is the most connected, and undergirds the very survival of electronics-dependent civilizations.

This report does not suggest creating a service component to organize, train, and equip for this environment, as these responsibilities can be, with the right emphasis, shared equally as new interservice training, operations, and standards pave the way for enhanced future operations within an existing service framework. However, it is feasible that better management of the electromagnetic domain can be later incorporated into a functional Cyber-EMS Combatant Command or an existing combatant command, such as Space Command, whose purpose would ultimately develop to exploit opportunities and mitigate risk at the nexus of space, cyberspace, and the EMS.

Finally, the future of the electromagnetic domain in competition and warfare will continue to blur, blend, fade, and set aside boundaries, which is why competitor efforts within the gray zone are strongly trending toward combined cyber-EMS activities. Thus, the use of EMS attack strategies within the gray zone may invariably change the very context of competition—yet again. From a comparison standpoint, imagine an army standing rank and file on a battlefield when, for the first time, war elephants emerge from the opposing side. This early "shock and awe" strategy not only caused battle-hardened soldiers to break formation but also caused psychological terror.

Similarly, the average person has become unconsciously dependent on the EMS to such a degree that the interruption of the EMS or EMS-dependent services will have both physical and psychological impacts. Thus, as part of broad education efforts, the public and government should be sensitized to the realistic prospect of both short- and long-term EMS outages and effects. By addressing these kinds of issues, the EDTF will continue thinking to win in the electromagnetic domain.

Joint Chiefs of Staff Questions with Task Force Findings

Within the context of the electromagnetic spectrum, the following questions were paramount to the Joint Chiefs of Staff. EDTF endeavored to provide in-depth answers to these questions against the backdrop of an intensive and technically feasible war game. The foundational premise of the war game was a significant electromagnetic attack on the 48 contiguous states.

The scenario encompassed elements of the Joint Force and large segments of US civil society and critical infrastructure. From the outset, it was apparent issues within the EMS cause many unanticipated second- and third-order effects. EMS issues that are limited in scope may rapidly translate into national issues with far-reaching effects, including the failure of transportation, food distribution systems, bulk-fuel and logistics systems, water purification and treatment, and communications and data-transmission systems. These failures were in part due to the ability of the EMS to be used as a tool to disrupt sensitive electronics that operate, run, mechanize, or govern modernized computer-based systems. Where such disruptions impacted the Joint Force, the effects often led to mission failure.

QUESTION 1: What are our strategic blind spots in regard to each track in a severe EMS-degraded environment,[10] and how should we place near-term bets to counter/frustrate enemy efforts?

Over the past 20 years, the strong migration from sturdy but cumbersome legacy systems toward efficient but delicate systems has increased—by an astonishing margin—US and allied vulnerabilities to various forms of electromagnetic disruption. Additionally, a number of novel systems such as 5G, the internet of things (IoT), artificial intelligence (AI)-controlled robotics, and space-based networks are introducing variables not yet well understood. As these elements are added to key system touch-points, complexities and blind spots are being introduced at a shocking pace. Coupled with the electromagnetic domain, hypernetworked modern systems-of-systems enable actors to take powerful advantage of opportunities to disrupt and destroy critical systems in all domains—simultaneously. In this way, modern adversaries are developing robust capabilities toward leveraging the EMS domain as powerfully as the first navy that harnessed steam power to move fleets. Even now, the true power of the electromagnetic domain is only tacitly understood. Once fully leveraged, this domain will enable total communications and information control in the twenty-first century. Such may lead to a state where the dominant feature of future warfare becomes electromagnetic warfare (EW). The utility of the EMS is such that competitor military writings speak of the EMS as a secret weapon confounding all aspects of a nation, including its diplomatic, informational, economic, and military (DIME) power.[11] For example, in 1999, the Central Intelligence Agency translated the writing of two influential Chinese colonels, Qiao Liang and Wang Xiangsui, who predicted:

Once fully leveraged, this domain will enable total communications and information control in the twenty-first century. Such may lead to a state where the dominant feature of future warfare becomes electromagnetic warfare (EW).

> The new concept of weapons will cause ordinary people and military men alike to be greatly astonished at the fact that commonplace things that are close to them can also

10. The tracks were as follows: (1) electromagnetic spectrum operations (EMSO), (2) high-powered electronics and microwaves (HPEM)/directed energy (DE)/spectrum management, (3) electromagnetic pulse (EMP) and geomagnetic disturbances (GMD); and (4) quantum and 5G technologies. In total, 17 teams were formed, including two special teams to address nuclear power station vulnerabilities and analysis of commercial reports and data sources associated with the electric power industry.

11. Qiao Liang and Wang Xiangsui, *Unrestricted Warfare* (Beijing: PLA Literature and Arts Publishing House, February 1999), 54, https://www.c4i.org/unrestricted.pdf.

> become weapons with which to engage in war. We believe that some morning people will awake to discover with surprise that quite a few gentle and kind things have begun to have offensive and lethal characteristics.[12]

It is compelling that the future utility of EMS was understood as far back as 1999 when this insight was penned. While there is little consensus as to whether or not the US and its allies are behind competitors in technology, there is little argument about the reality that US competitors are demonstrating a more complete understanding of the promise and potential of the EMS as a domain of warfare. Like the tortoise and the hare, the US as the hare has rested too long due to confidence in its initial sprint to the leading edge of capability. What follows is a brief review of how EMS is being applied to the instruments of DIME power from within the gray zone (activities below the threshold of war).

Diplomatic

In 2018, the EDTF examined EMS events and technologies that affected US embassy staffs in Cuba and China starting sometime in 2016. During a series of events unfolding over many months, diplomatic staff members were diagnosed with traumatic brain injuries (TBI), injuries typically associated with some sort of shock or blow to the skull.[13] Analysis and testing demonstrated that the internal temperature of the victims' brains had been raised by an external electromagnetic source, triggering a response similar to concussive injuries.[14] While there is no doubt the capabilities and technologies needed to conduct this kind of operation exist, these were the first instances of use against nonmilitary diplomatic staff. In keeping with activities falling

If the US continues to pursue the creation of 5G networks, planners should give full consideration to the fact they will be providing a less resilient telecommunications system. Use of this knowledge can afford planners the ability to build in resilience and mitigate vulnerabilities, up front.

12. Liang and Xiangsui, *Unrestricted Warfare*, 26.

13. Maggie Fox, "Cuban Embassy Staff Had Concussion-Like Injuries, Doctors Say," NBC News, 15 February 2018, https://www.nbcnews.com/health/health-news/cuban-embassy-staff-had-concussion-injuries-doctors-say-n848291; and Emily Rauhala and Carol Morello, "State Department Warns US Citizens in China after Employee Suffers Possible Sonic Attack," *Washington Post*, 23 May 2018, https://www.washingtonpost.com/world/asia_pacific/state-department-warns-us-citizens-in-china-after-employee-suffers-possible-sonic-attack/2018/05/23/db7bbd44-5e68-11e8-8c93-8cf33c21da8d_story.html?utm_term=.3c2618446f25.

14. William J. Broad, "Microwave Weapons Are Prime Suspect in Ills of U.S. Embassy Workers," *New York Times*, 1 September 2018, https://www.nytimes.com/2018/09/01/science/sonic-attack-cuba-microwave.html.

below the threshold of war, these unknown actors demonstrated an ability to shape environments in a nonattributable way, a case study that will likely inspire other able actors to use similar means to influence targets.

China has demonstrated a willingness to use its diplomatic ties to create economic codependencies that will further widen EMS vulnerabilities. By providing 5G subsidies to nations at rates up to 10 times higher than Western companies, China has used liberal government funding to propel its Belt and Road Initiative. There is wide consensus that the 5G network is a major strategic play to create an infrastructure within the US and allied nations that will provide ultra-high-value services. But it will also allow competitive access to the private and secure information on those same networks. This knowledge is why the US government recently blocked the sale of Chinese-manufactured 5G technologies within the United States. During EDTF, 5G technology was assessed to create unique vulnerabilities on two fronts: (1) resilience and (2) dual uses (the military use of civil technologies). Only the first vulnerability will be discussed in this report.

For all the advertised benefits of new technologies, there tend to be second- and third-order effects or unintended consequences once implementation occurs. Most of the time, these latent issues are not evaluated prior to implementation. But for perhaps the first time in the history of infrastructure development, the US and the world have an opportunity to understand the potential consequences up front. In particular, the 5G network can be thought of as handfuls of small pebbles being thrown into a pond, creating dozens of small ripples, while the 4G network can be thought of as throwing one or two large stones in a pond, creating a couple of big waves. From a broadcasting standpoint, 5G cell sites can have a signal range of only about 2,000 meters. This limited area of signal propagation requires a higher number (or higher density) of sites to achieve network coverage. On the other hand, 4G tends to be deployed at lower frequencies and enjoys much greater coverage. This allows ample network coverage with fewer towers. However, to achieve 5G coverage over an area the size of the United States will require tens of millions of 5G sites as opposed to several million 4G sites.

The sheer number of 5G sites needed to achieve broad coverage makes any 5G network difficult to protect from EMS interruption. For example, larger 4G towers are often supplied with a generator and battery backup systems to ensure reliability. Retroactively providing the same resilience to tens of millions of small 5G sites is not practical. Thus, if the US continues to pursue the creation of 5G networks, planners should give full consideration to the fact they will be providing a less resilient telecommunications system. Use of this knowledge can afford planners the ability to build in resilience and mitigate vulnerabilities, up front. It must be understood that if this is not accomplished, the 4G infrastructure that underpins the 5G may be increasingly critical. It might be the case that the 4G network should be kept in place longer in order to provide this level of resiliency.

An example of this hindsight can be seen with GPS. This context is provided with the understanding that with 5G, as with GPS, underlying older and more resilient legacy systems will eventually be dismantled. As the US transportation system became more dependent on reliable GPS, many of the analog navigational aids that formed the original navigation system for aircraft began to be defunded and dismantled. Today, however, as our understanding of natural and man-made GPS vulnerabilities evolves, there is an understanding that analog navigation aids may actually serve well as resilient and GMD-hardened backup systems. Similar consideration should be given to both landlines and 4G systems. However, as the next section will discuss, the security of the US 4G network may already be compromised.

Informational

There is no denying the US and its allies have been the prime targets of intentional and persistent influence operations that leverage information and even white noise (i.e., fake news) to manipulate perceptions and distract the public. However, where the electromagnetic domain is concerned, this condition may be more dangerous than previously understood. Currently there is an overarching belief in wider society that, despite efforts to disrupt the US and allied aspects of DIME, these activities will not cause long-term harm. This narrative is often based on the premise that competitors like China would not harm a close trading partner or can be persuaded to act always in accordance with international law. In some respects, there is a dangerous naiveté about the degree to which the US is in a competition with powers that seek to usurp the Westphalian system[15] as a whole. Of late, EDTF members have been asked by high-level officials within government, "how can China be per-

15. Richard Coggins, "Westphalian State System," abstract, *The Concise Oxford Dictionary of Politics*, 3rd ed., 2018. Author's note: "[A] term used in international relations, supposedly arising from the Treaties of Westphalia in 1648 which ended the Thirty Years War. It is generally held to mean a system of states or international society comprising sovereign state entities possessing the monopoly of force within their mutually recognized territories. Relations between states are conducted by means of formal diplomatic ties between heads of state and governments, and international law consists of treaties made (and broken) by those sovereign entities. The term implies a separation of the domestic and international spheres, such that states may not legitimately intervene in the domestic affairs of another, whether in the pursuit of self-interest or by appeal to a higher notion of sovereignty, be it religion, ideology, or other supranational ideal. In this sense the term differentiates the 'modern' state system from earlier models, such as the Holy Roman Empire or the Ottoman Empire."

suaded to use AI in a responsible way that does not violate human rights?" While such ideas may be well intended, such thinking is based in primacy of learning and serves the purposes of disciplined competitors by working against realities. The willingness of China and other actors to set aside the current order to achieve tactical, operational, and strategic objectives is well demonstrated. However, as finite assets, manpower, and time are expended on ineffectual efforts, the objectives of competitors are well served—even if unwittingly. In short, it will always serve a competitor's interest when US or NATO efforts are inert.

Whether it is China illegally expanding territories into the commercial and territorial commons of other provinces in the South China Sea or using lasers to force allied military aircraft to land[16] or Russia using state-controlled poisons to assassinate dissidents and gray zone warfare to illegally annex territories, the brilliant use of controlled narratives has become exceedingly serious. This behavior may be catalytic as other actors increasingly see the benefits and utility demonstrated with increasing success: "In particular, since gray zone actors may be unaware of or ignore [US and] NATO dispositions with respect to the gray zone, actors may perceive this area as abandoned. Such may then reinforce the idea of unimpeded access, which in turn may inspire the pursuit of even greater ambitions."[17]

Economic

Within the United States, there is a significant risk that insurgent economic campaigns have matured to the extent that influence operations can, in some cases, prevent corrective actions. It is a well-known fact that China holds ownership of nearly 70 percent of rural America's telecommunications networks. While this is a strategic risk in and of itself, the EDTF asserts that if China has the foresight to invest in critical communications infrastructure, other infrastructure, including the electric power grid, may also manifest like vulnerabilities. In light of this, it is not unrealistic to consider that if federal action becomes a requirement to enhance the protection and resilience of the wider US bulk power grid, which is

In this way, the United States and its allies must guard against patient Trojan horse strategies designed to compromise security and stability over decades. The detection of such strategies is especially important when any critical infrastructure is concerned.

16. "Australian Navy Pilots Struck by Lasers in South China Sea," Associated Press, 28 May 2019, https://www.apnews.com/e7a2592d30d743ddaecf4bf20324d55e.

17. Stuckenberg, "Deterrence in the Gray Zone," 149–50.

composed of nearly 3,000 private companies, China's influences could, through strong financial and leadership positions in owned companies, compromise or impede federal efforts.

Richard Danzig et al. note:

> China and Russia have been faster than the United States to grasp that they are engaged in a multifaceted strategic competition. Their more comprehensive approach is evident in their use of intelligence campaigns against technological and economic targets, government orchestration of their commercial sectors, pressure on foreign companies to share data and technologies as a prerequisite to access their domestic markets, and, in China's case, long-term funding of critical technologies and the use of trade, aid, and loans as a means of building relationships.[18]

In this regard, China's strategy has often been compared to the tarantula hawk wasp.[19] While the wasp is small, it possesses one of the most painful stings in the animal kingdom. When it stings its prey, the tarantula is incapacitated. The wasp then lays eggs inside the tarantula, which later hatch–killing the host. However, this illustration does not accurately portray the strategic reality. This is in part because once the tarantula is stung by the wasp, it is aware of it. If the United States is akin to the tarantula, most do not recognize that we have been stung. Rather than a wasp, China's strategy resembles instead a microfungus called cordyceps.[20] Cordyceps reproduces via spores that migrate into the central nervous system of the host. Once it takes over the host, it will direct the host to the point of perfect sunlight, temperature, and humidity and then kill the nutrient-rich host in the ideal place to nurture further growth and reproduction; such may also be accomplished with states.[21] In this way, the United States and its allies must guard against patient Trojan horse strategies designed to compromise security and stability over decades. The detection of such strategies is especially important where critical infrastructure is concerned.

Military

As the Joint Force becomes increasingly sophisticated, it also becomes more reliant on technologies. For instance, in an effort to ensure information relevance at the speed of decision-making and to alleviate certain risks, there

18. Richard Danzig, John Allen, Phil DePoy, Lisa Disbrow, James Gosler, Avril Haines, Samuel Locklear, James Miller, James Stavridis, Paul Stockton, and Robert Work, *A Preface to Strategy: The Foundations of American National Security* (Laurel, MD: Johns Hopkins University Applied Physics Laboratory, 2018), 31, https://www.jhuapl.edu/Content/documents/PrefaceToStrategy.pdf.

19. Danzig et al., *A Preface to Strategy*.

20. Stuckenberg, "Deterrence in the Gray Zone," 131.

21. Stuckenberg, "Deterrence in the Gray Zone," 131.

has been a movement to upload most unclassified DOD data to the cloud. However, because cloud networks rely on normal network hardware, where the EMS is concerned, such networks still carry risks. Although a secure server warehouse may be well protected from a variety of challenges both cyber and physical, the ability to access or destroy data—even when air gapped (an absence of a direct or indirect connection between a computer and the internet, effected for security reasons) to provide a measure of protection—means the value of such measures is being set aside through electromagnetic developments. An analogy can be drawn between this electronic evolution and the use of wood palisades (defensive walls used for protection). From early history, such barriers were raised by militaries and communities as a response to threats. However, once actors determined wooden walls could be set fire, the next generation in protective wall technology developed–the stone wall. To overcome stone walls, actors began digging under the foundations to cause collapse. As a countermeasure to mining, moats were dug and filled with water. Similar developments have been present with almost all technologies. However, there has scarcely been a time, when, despite gaps and moats, the attacker could not eventually succeed. But such conditions are rapidly changing. In this way, military network security measures may one day require robust signal hardening[22] or counterelectromagnetic fields to prevent adversary signal penetration and information network compromise. While new vulnerabilities are emerging, it is critically important to note that most systems remain unprotected even from well-known EMS threats such as EMP.

While EMP is often thought of as a short burst of energy arising from a nuclear detonation at altitude, such a pulse can also be generated by portable units such as those envisioned in the movie *Ocean's Eleven*.[23] Portable EMP systems have long been available to the public in the form of briefcases used to test signal-hardened buildings and facilities. It is conceivable that, in the future, EMP missiles may be designed and/or

In this way, military network security measures may one day require robust signal hardening or counterelectromagnetic fields to prevent adversary signal penetration and information network compromise.

22. Signal hardening is presently done on US Nuclear Command and Control systems to prevent EMP disruption; for instance, minimum performance requirements for low-risk protection from mission-aborting damage or upset due to high-altitude electromagnetic pulse (HEMP) threat environments are defined in MIL-STD-2169.

23. "EMP (Electromagnetic Pulse)," *Ocean's Eleven*, directed by Steven Soderbergh (Burbank, CA: Warner Brothers, 2001), https://www.youtube.com/watch?v=jrA-1cG_wq4.

employed to disrupt sensitive equipment aboard military aircraft. In the case of commercial aircraft, disruptions may be caused with less sophisticated means such as employing portable electromagnetic devices to disrupt navigation and fly-by-wire systems.

The opportunities for potential use of EMS for aggravated disruptions to modern systems are extensive and, in every way, on par with or even more potentially deadly than many of today's cyber and kinetic vulnerabilities. It should be noted that China has indicated it intends to develop substantial EMS capabilities in space. Such capabilities include both military and civilian applications, including space-based solar power, directed energy weapons, and lasers. While such ambitions might be dismissed, it should be noted that China has not missed a major space development benchmark since the 1980s. If such capabilities are developed for dual use, it is foreseeable that space-based assets could, in the future, serve to enforce access and denial operations. For instance, the ability to harvest solar energy without interruption can feasibly power weapons used to deny human access to communities and cities. Such can be thought of as geo-fencing but with directed or microwave energy. The same possibilities exist for space-based lasers, which could harass both commercial and nonmilitary ground-based or space-based assets.

Information Isolation

There was broad consensus among EDTF Fellows that a systemic lack of information sharing between the DOD and industry partners has led to gross misunderstandings regarding the scope and severity of EMS vulnerabilities. In some instances, there is a complete absence of knowledge. Such is especially true with respect to EMP. For example, participants noted that there is no common understanding of immediate, intermediate, and residual EMP effects on national, defense, and state systems and capabilities. While irrefutable EMP research exists (both at classified and unclassified levels), rapid changes in technology and the misinterpretation of research, potentially arising of adversary influence operations, have led to dangerous and lingering misconceptions about EMS. These misconceptions are a contributing factor in the long-standing absence of needed action. Blind spots arising from information isolation and misinformation may be addressed through the exercise of accountable leadership and information sharing and through rigorous peer review by authoritative experts.

Another point raised during deliberations relates to sharing novel technical solutions. Several companies and partners offered that there can be a reluctance to distribute proprietary data out of concern for protecting intellectual property from adversary compromise. One proposed solution was to develop a streamlined patent process for national security–related technologies to allow IP protection and faster integration of new ideas into discussions, planning, and technologies that enhance electromagnetic resilience.

It was also noted that there is no clearinghouse or repository listing or linking EMS projects across DOD, industry, or government. The absence of a focal point leads to redundancy, reduces the opportunity for collaboration, and inhibits benchmarking. Additionally, fellows noted that institutional knowledge from previous EMP testing is rapidly disappearing—including data from nuclear testing during the 1950s, which cannot be digitized. This information should be captured and preserved in a secure repository to aid ongoing research and development. This repository should not only include historical data but also results from recent tests or simulations with modern electronics.

Finally, with respect to information isolation, the development of cross-organization information-sharing programs and a common language (definitions) are of paramount importance. Given the moratorium on above-ground nuclear weapons testing, information sharing and common definitions are necessary to build models and simulations to validate theories and claims. Furthermore, the DOD should reexamine classification controls and, where possible, downgrade and declassify in order to share findings and theories with industry and academia. Such a need became particularly evident when one of the leading technology companies in the United States acknowledged it had no idea about EMS risks associated with 5G or EMP. It was acknowledged that a flash bulletin system such as the Federal Bureau of Investigation's "Most Wanted" list could provide value by ensuring industry and academic entities possessing a national security role can stay timely informed. Along with this bulletin would be the provision of appropriate level clearances to decision-level staff.

Public Support

Another recurring theme during the conference was the acknowledgment that during the Cold War, the threat of attack on the contiguous United States was taken seriously and that the public, civic leaders, military leadership, academia, and industry actively requested information regarding threats and mitigating steps (i.e., bomb shelters, drills, etc.). Participants argued that "user pull" (public requests for action) will not happen until the nation realizes how EMS events may impact society. This idea returns to primacy of learning. In the most recent case, most Americans dismiss the possibility of a strategic attack on the homeland. Such views have been reinforced by false information and sensational media, all of which have hindered efforts to ensure the wider US is prepared for an electromagnetic event, whether through EMP or GMD.

A recommendation for how to address this climate would be to launch a public service information campaign. These "Smokey Bear" campaigns could inform the nation of the need to become more resilient,[24] which could then extend to local community exercises. Additionally, participant discussions indicated that the military must continue to lead the way by developing a broad EMS-aware culture.

Strategy and Recovery Plan

The lack of an existing national and military plan to recover and retaliate from an EMP attack was an additional strategic blind spot. A nationwide plan, collaboratively led by both the Department of Homeland Security (DHS) and US Northern Command (USNORTHCOM), should be developed and exercised on a regular schedule. This plan should be integrated into local community exercise programs and used as means of educating the wider public on risks. Local emergency operations centers need to understand and prioritize recovery efforts and resources. It is likely nuclear power stations, airports, and hospitals will be the priority for the restoration of electricity during EMS disruptions to avoid long-term impacts to society and the nation's ecology.

Societal Psychology

Depending on the effects of an EMS attack, it is possible to see the breakdown of societal norms in as little as 72 hours. An example provided was the looting that occurred after Hurricane Katrina. Before beginning any official planning, planners must holistically understand the operating environment. Researching the psychology of human desperation, starvation, and living without the rule of law is vital to every emergency planner, especially when planning for a long-term blackout scenario. Any plan of action must provide a relatively safe environment for the people whom the plan depends on, including immediate families, for the plan to succeed. Additionally, a long-term plan to provide food, medical care, and housing, and so forth is necessary (an outline for this kind of plan may be found in the 2018 EDTF report, appendix 6: "Bullet Background Paper on Black Start Teams").

24. Author's Note: Smokey Bear is a national advertising campaign initiated by the US Forest Service in 1944; widely recognizable from television commercials and billboards, the bear mascot wears a forest service cap and says, "Only YOU can prevent forest fires." US Forest Service, 4 August 2014, https://www.fs.fed.us/features/story-smokey-bear.

EDTF recommends planners not only focus on a blackout emergency plan for the first two weeks but also plan for situations that last longer. This topic is further discussed in appendix 7: "EMS Resilience and Preparedness for Government and Society."

QUESTION 2: How can industry, academia, and military work together to counter our strategic blind spots and improve the nation's resilience?

Build a Community of Experts

To counter our strategic blind spots and improve the nation's resilience, we must include industry, energy companies, and data analysis personnel in the research and development of capability. We should invest in science, technology, engineering, and mathematics (STEM) as a public education baseline, as it will be required to support defense against EMP. In particular, few universities in the United States have specific training or education programs that encompass the cross-disciplinary aspects needed to deeply understand the physics, engineering, and mechanics of EMS hardening. Such programs should be developed with speed and intention. Parties interested in this topic should contact EDTF as the task force continues to expand its ecosystem. In particular, EDTF is interested in civilian and military fellows and subject matter experts from the following organizations: Air Force Institute of Technology (AFIT); Air Force Studies, Analysis, and Assessments (AF/A9); Air Force Office of Scientific Research; nongovernmental organizations (NGO) focused on EMS; and similar agencies.[25]

In the realm of academia, military elements may reinvigorate potential options such as Palace Acquire, which sets a career path for recruited STEM graduates. Additionally, programs should also engage younger teens (not just college graduates and not just for recruiting in the military, but also for the DOD civilian and contractor force).

The EDTF summits have created a variety of opportunities for military, industry, academia, scientific, and government leaders to discuss and collaborate on ways to mitigate EMS related threats facing the US and NATO. What is more, it has spawned efforts to address them throughout the country. One example is an effort taking place in San Antonio, Texas.

Under the direction of the commander of the US Air Force Air Education and Training Command (AETC), a team formed using activated Air National Guard personnel to research and collaborate with military and community partners to locally implement EDTF recommendations. This innovative

25. The EDTF has established a virtual working group at All Partners Access Network (APAN) Community (https://community.apan.org) to establish contact and share information across an expanding network. Anyone may request access to the group "EDTF" once they have received an APAN account.

approach itself was the result of recommendations from EDTF 1.0 to utilize a "test city" to implement an action plan based on collaboration between the DOD and the local community to harden a base and surrounding community. In this case, the test city is San Antonio, and the DOD component is composed of the 11 installations that make up the Joint Base San Antonio (JBSA) complex.

The team is called the JBSA-Electromagnetic Defense Initiative (JBSA-EDI), and its mission statement is to "educate, collaborate, and facilitate electromagnetic spectrum operations (EMSO) of mutual interest to the JBSA civilian and military communities." To that end, JBSA-EDI has developed a strategy and collaborative partnerships with the following lines of effort:

- Infrastructure resiliency against effects from man-made or natural EMP
- 5G network implementation risk awareness and mitigation
- Electromagnetic spectrum operations policy, doctrine and education development
- Local and state strategic planning for long-term regional power grid-down scenarios

Each line of effort is based on lessons learned or recommendations from both the 2018 and 2019 EDTF summits. Collaborative partnerships between JBSA, its mission partners, local power, gas and water utilities, local and national research institutes, academic institutions, and state agencies formed quickly. One important lesson learned is that concerns highlighted by EDTF are known throughout military, government, and civilian communities. There is widespread desire to confront and mitigate the risk from EMS threats, but without leadership to provide a catalyst for action, most organizations and institutions are unsure of their roles and responsibilities. In the San Antonio example, the JBSA-EDI is providing the catalyst and coordination that military, industry, and local government partners have quickly rallied around. While still in the research and exploratory stage, JBSA-EDI has already made an impact organizing a workshop with 50+ participants representing more than 30 military and civilian organizations. Working groups have formed around the four lines of effort, and quarterly meetings are planned to report progress and facilitate additional collaborations. The progress of this test city will be briefed at future EDTF summits.

Other lines of effort have formed in Alabama, South Carolina, and Wyoming and are now starting to integrate across similar projects due to the efforts of the EDTF. One desired and necessary outcome of the EDTF is that other "Electromagnetic Defense Initiative" style efforts form throughout the country, each focusing on the risks and opportunities relevant to their particular location and circumstance.

Understand Dissuasion[26]

During EDTF 2.0, there was consensus that reliance on traditional deterrence constructs such as the nuclear umbrella may be woefully insufficient to prevent strategic EMS attacks. One of the reasons deterrence may be insufficient is that it relies upon attribution (knowing who attacked). Without knowledge of who attacked, the ability to retaliate is limited or nonexistent. At the fundamental level of deterrence theory, if an actor has no ability to retaliate, there is no credibility. Hence, attackers may be emboldened to act if they are convinced there may be no penalty. Consequently,

A close cousin of deterrence, the art of dissuasion is a required study in response to the limitations of deterrence when limited attribution is a realistic prospect.

> In the wake of the Cold War, tensions relaxed and many of the technological capabilities once exclusive to states were diffused to state and non-state actors alike. In place of the bipolar system, a complex and chaotic system of geopolitical and military interactions has emerged.
>
> In this emerging space, no few strategic threats may be presented by way of artful military strategy and technological creativity. Moreover, certain perplexing strategic activities can be difficult or impossible to attribute and, thus, increasingly difficult to deter. This contemporary conflict space is often called the "gray zone." The inability to deter strategic attacks within the gray zone is a potentially severe limitation of deterrence within the contemporary defense context.
>
> One potential method of preventing strategic enemy actions from within the gray zone is to ensure resilience is built into the national infrastructure of all alliance members. In this way, a state will not need to maintain the status quo through fear of retaliation or pain (which may be hard to levy when you don't know who will carry out an act), but rather diminish risk of action through a very non-specific form of general deterrence. Where more assurance is needed, however, dissuasion is the only strategy with application in the gray zone where an actor uses opacity to conceal strategic actions.

26. This section is adapted from comments presented by David Stuckenberg at King's College London, 18 January 2019: "Re-orienting NATO Deterrence: The Reality of Strategic Gray Zone Threats." Paper presented at SAS-141 Research Symposium on Deterrence & Assurance within an Alliance Framework, King's College London, UK, 17–18 January 2019, https://www.sto.nato.int/publications/STO%20Meeting%20Proceedings/STO-MP-SAS-141/MP-SAS-141-16.pdf.

> A close cousin of deterrence, the art of dissuasion is a required study in response to the limitations of deterrence when limited attribution is a realistic prospect. Dissuasion may altogether remove the incentive for an adversary to act when deterrence cannot apply due to an inability to hold an actor at risk. Rather than keeping the status quo through a prolonged and often progressive contest of pain (hard power), dissuasion is a soft-power strategy that gets to the heart of an actor's motivation calculus. By analogy, if deterrence prevents action by threatening punishment for taking a cookie out of a container, dissuasion reinforces the idea that there is no cookie in the container to begin with, therefore an actor may never be tempted to take a cookie.
>
> Therefore, dissuasion works to prevent action by removing the enticement to act in the first place. In other words, if actors cannot achieve their desired ends—why would such act at all? In the case of a power grid, if such were hardened against [high-altitude electromagnetic pulse (HEMP)], an actor may never consider the strategic use of a HEMP as it would not have catastrophic consequences. Thus, dissuasion is a contest that seeks to remove an actor's motivation to act rather than, as with deterrence, create a fear or hold at risk to those who may have the desire or occasion to act. As a form of strategic influence, dissuasion has profound utility in the gray zone where deterrence is often misapplied or overrelied upon to prevent able actors from acting.[27]

Develop a Strategic Plan

A strategic-level plan, from deterrence to recovery, will require participation from all elements of government and industry. Cohesiveness and agreement may be difficult to obtain, as responsibilities often shift depending on the source of the EMS interference. DOD, industry, and academia must determine which organization will take charge in which situation. Organizations must have integrated exercises and testing for various plans. Furthermore, strategic planners must work with local planners to ensure the nation's resilience at the community level.

When developing a national strategy, standardized terms and definitions are important when determining responsibilities. "EMP" insinuates a nuclear detonation, "GMD" insinuates a natural occurrence, and "electromagnetic attack" describes the use of a localized weapon conducting intentional electromagnetic interference (IEMI). It is recommended that the Federal Emergency Management Agency (FEMA) classify GMD and EMP as natural disasters and that FEMA be included in future EDTF summits and EMP research events. It is also recommended that FEMA be tasked to respond to wide regional events if the power grid were destroyed.

It is also recommended that the DOD institute readiness reporting for critical assets to provide a good understanding of what will be available and function-

27. Stuckenberg, "Re-orienting NATO Deterrance."

ing after an EMS attack. To do this, DOD installation commanders will need to have an understanding of not just organic assets but all critical infrastructure functions supporting an installation's essential operations and the EMS vulnerabilities created by those dependencies. Since DOD maintains the nation's most proven EMP hardening standards, it must not only define hardening requirements for organic mission sets and provide readiness standards for reporting but must also engage local civilian critical infrastructure owners, operators, and/or partners with this information to help them determine how to harden their assets as well. In some cases, federal funding to support local critical infrastructure improvement may be required.

An additional recommendation to consider is a policy that would establish critical electrical power generation networks that can be federalized during a threat by GMD or EMP. The precedent for such actions exists in the commercial airline industry program called the Civil Reserve Air Fleet (CRAF). During a national crisis, US air carriers may have a percentage of their aircraft federalized to provide surge airlift and logistics capabilities to the DOD. Establishing an equivalent program for US power utility companies could not only buy down risk for power companies during crisis, it could also help fund additional technologies needed to protect the key infrastructure surrounding major US cities and manufacturing centers (by providing additional funding to power utility companies).

Numerous EDTF personnel working on pilot projects at the local level with electric utilities have witnessed a trend where industry partners cite industry-funded EMS or EMP research as a basis for planning and strategy. Such research includes sometimes questionable research associated with the Electric Power Research Institute (EPRI). These observations became more compelling as EDTF 2.0 convened, as EPRI released a report on EMP on the second day of the summit. Since the task force had a working group consisting of the world's foremost EMP experts digesting reports and data, the task force was able to review the EPRI report in detail. *The EDTF has determined* that *reliance on the EPRI report could result in a lack of critical infrastructure protection, particularly extra high voltage (EHV) transformers and long-lead-time replacement items required for the power grid to function.*

It is important to note that telecom service providers have established procedures for catastrophic events such as hurricanes, earthquakes, volcanoes, and power outages; the next step would be to test and include EMP resilience. Such testing should be well considered in light of the previous discussion of 4G and 5G network vulnerabilities. Planners should determine which equipment has been tested for EMP and work together on solutions to address the most vulnerable parts of the network first. An agile infrastructure can include portable, geographically dispersed systems (like mobile base stations called "cells-on-wheels") or additional deployable nodes in the form of drones or balloons. To help facilitate the rollout of EMS resilient requirements, federal statutes should also require that requests for information/proposals associated with these types of infrastructure consider EMS hardening standards and requirements.

Finally, there is a need to continue advocacy for Black Start programs and capabilities. These teams can assist civilian companies in restarting certain power facilities powering critical government functions. In addition, teams should have a post-event plan to move to and survey predetermined high-voltage transformers in critical locations. Such inspections are vital information to gather within 24–48 hours to determine the extent of damage and generate an estimate of service outage duration. Such information is vital to ensuring that the correct national contingency plan is implemented.

Incentivize Industry

EMS resilience demands innovative service providers willing to invest in enhancing their network security. Beside cybersecurity concerns, mobile service providers place a high priority on service continuity, as they continually face issues of network restoration after power outages and disruptions. The military community must better engage industry regarding system redundancy and resilience and industry's plans to ensure both with the advent of 5G.

One recommendation was to develop an EMS-Star rating that scores companies based on how well they conform to certain EMS hardening standards. Inspired by the Energy Star program run by the US Environmental Protection Agency to promote energy efficiency and awareness, the EMS-Star would incentivize companies to increase their EMS resilience in order to increase their score. These scores can be used in the acquisition process for DOD or "military-grade" EMS shielding. Such programs could also be expanded to reward cities for completion of EMS resilience programs.

Figure 2. The Energy Star logo

In summary, the DOD needs to lead the way by setting the requirements for military-grade EMP hardening. These standards must ensure normal operations during an EMP event and allow the military to support local emergency operations trans- and post-event and retaliate if necessary.

Finally, academia must develop and revitalize EMS programs, incentivize engineering disciplines, and ensure security protocols are in place so that proprietary and national security–oriented research at universities and labs remains within the US and is available only to US citizens and vetted allied personnel.

QUESTION 3: Are quantum and 5G communications resilient to threats within the EMS?

5G is not just an extension of 4G cellular networks but rather a convergence of 5G mobility, the IoT, and AI. Additionally, 5G can enable very low latency, meaning almost no delay in receiving signals. This will enable real-time, mission-critical operation and control. We have never before experienced these extreme capabilities simultaneously. Together, these elements will promote new applications and businesses previously impossible to imagine. While the discussion focused mainly on 5G, quantum communications are just as vulnerable to EMS attack because they do not circumvent the transmitter and receiver vulnerabilities of more traditional communications capabilities unless effectively EMS hardened. The translation of information using quantum entanglement, however, is not currently, from a theoretical standpoint, subject to EMS interference.

The exceptional attributes of quantum entanglement should drive further research to discover how communications can advance uninterruptible secure communications and information transfer in a contested electromagnetic domain. In this respect, it is clear the properties of quantum entanglement will have widespread implications. Presently, China and Germany have both pioneered in development of drones that use quantum entanglement to operate and relay communications and information. The rapid maturation of quantum communications technologies presents the realistic prospect of transmission or "broadcast-free" control networks in as little as five to 10 years. The advantages arising of proliferated quantum technologies to future battlefields are sobering and may afford friendly and adversary nations with an ability to operate drones and precision-guided weapons and to send and receive communications even in a EMS-denied environment.

Developments in quantum communications networks and 5G networks will begin deployment in 2019 and continue expansion throughout the next decade. As 5G becomes an intrinsic part of the nation's infrastructure, there must be continued evaluation of how to take effective action to protect ourselves from hostile entities that would want to exploit, control, or undermine these capabilities.

Ultimately, if the 5G network deployed in the United States is not designed and constructed to be inherently resilient to EMS threats, and the electric power assets sustaining this network are not resilient to EMS threats, our nation will face an even more profound vulnerability than the status quo.

Although EDTF 5G working groups included leading government and industry participants, a necessary next step is validating the review with technical experts in the field to better understand what has already been done and then collaborate on steps to raise awareness and enhance all aspects of prevention, mitigation, and network recovery. This needs to be a focused effort that includes all mobile service providers, applications developers, equipment vendors, military planners, and those involved in disaster preparedness.

The Potential Impact Caused by an Electromagnetic Attack

A large-scale electromagnetic attack that knocks out a region's power would significantly degrade the existing mobile communications network, as all portions of the network are dependent on external power. This will be especially true for 5G, which relies on large quantities of small cells that are connected to lampposts, utility poles, and rooftops and do not have backup power systems. However, 4G is vulnerable to external power fluctuations as well. Although the larger towers and base stations may have backup power systems, if some of these locations cease to operate, neighboring locations pick up some of their load, which can overwhelm surviving cells, taking them offline as well. Another concern from an electromagnetic attack is the optical transmission that could be disabled if an associated base station or link is impacted. Again, power would continue to be a critical dependency.

In a 5G network, more of the processing will take place closer to the base stations or even in the cloud. With a traditional design, these base stations will not operate if they are not connected in some way to the core, which is necessary for the control of the network. Ultimately, if the 5G network that deploys in the United States is not designed and constructed to be inherently resilient to EMS threats, and the electric power assets sustaining this network are not resilient to EMS threats, our nation will face an even more profound vulnerability than the status quo.

Industry representatives at the conference postulated that adding resiliency after the initial infrastructure build would likely be 10 times more expensive than designing resilience in from the start. Because there is an understanding of the vulnerabilities on the front side of the network deployment, there is a unique opportunity to "design-in" EMS resilience at the beginning. EDTF suggests this should be done immediately with the deployment of the FirstNet 5G infrastructure as a proof of concept for the rest of the 5G infrastructure.

FirstNet is a Department of Commerce initiative authorized by Congress in 2012 to develop, build, and operate a nationwide broadband network for first responders. Since the current 5G network associated with the FirstNet emergency communications system is not EMP hardened, this vulnerability should be immediately remedied. Moreover, because 5G will eventually impact all aspects of society, the 5G network should be considered an integral part of a national response after an EMS attack or impact. The framework would bring local and state governments together with time- or event-phased plans that do not rely on outside inputs or robust communications among nodes. NATO partners should be made part of this plan. The plan should focus on rebuilding networks from the outside in with close coordination with the electric and telecom industries.

The Potential Impact Caused by an Attack from Within the Network

Present-day communications networks face daily cyberattacks and back doors to either capture information or disable capabilities. In the future, 5G will be connected to billions rather than millions of people and things—this will include access to a nation's vital infrastructure and information. Therefore, it is essential to establish a trusted network free of possible attack points. An attack on a network from within could have debilitating effects similar to an electromagnetic attack. Even more alarming is how access from within the network could enable an adversary to collect or manipulate information on the network without detection or fingerprints. This has been a concern with 4G, but with 5G, there will be more equipment and entry points on the network. These entry points will be difficult to monitor due to the massive volume of data and the dramatic increase of nodes.

Prevention and Mitigation

Given the forecasted scale of 5G network deployment and its capabilities, interconnectivity, and unlimited potential as an information and communications corridor for the economy, protecting 5G is paramount. EDTF teams discussed multiple prospective actions to maximize 5G's potential and settled on the following overarching recommendations:

1. Ensure uninterrupted access
2. Assure financial viability
3. Increase consumer and industry understanding
4. Secure network resilience
5. Conduct R&D in quantum and applications in next-next generation networks such as 6G

Also, while not specific to 5G, a few interrelated points such as EMS domain recognition and DOD accessions will help underpin 5G's success and are therefore also addressed below.

First, to ensure unfettered access and in accordance with presidential and other senior US governmental guidance, the 5G network must be free of state-controlled equipment. Even under strict supervision, no service provider or government can ensure a mobile vendor is not manipulating or controlling information being transported over their networks. These mobile vendors have the systemic capability to allow, willing or unwilling, backdoor access into the network through design and servicing. This is especially a concern with equipment produced by Chinese companies since the Chinese government has the ability to force Chinese companies to comply with broad and sweeping intelligence collection directives. Therefore, the US government (USG) requires everything it buys to be free of state-controlled equipment, such as equipment provided by China's telecommunications vendors Huawei and ZTE. The USG is highlighting these vulnerabilities to other countries and encouraging them to adopt policies that restrict the proliferation of Chinese 5G technologies.

Similarly, and equally important, supply chain integrity is vital. It will take a concerted effort to assess the security and vulnerability of each product and component integral to the end-to-end supply chain. Even non-state-controlled mobility equipment vendors like Ericsson and Nokia manufacture equipment in China. Consequently, the USG must work with each of these companies to require supply chain integrity and procedures. Another critical action is to work with the standards bodies, equipment vendors, service providers, and security corporations to improve network-level data security and encryption. A form of deterrence is to institute significant trade tariffs on any country or company found to introduce backdoors or other serious security vulnerabilities.

Since none of these precautions will be foolproof, Western states must establish a "zero-trust model" to mitigate vulnerabilities. The DOD should also plan to move to quantum-resistant key exchange mechanisms to deal with the eventual fall of public key exchange algorithms, particularly given China's investments in quantum computing. All of industry must work together to develop innovative processes enhancing security encryption capabilities. It is essential to continue to work with other nations, encouraging them to adopt similar policies so as to limit the detrimental impact on our global connected societies.

The advent of quantum communications makes the concept of quantum-based malware very interesting. In this regard, a nonsecure supplier could potentially add entangled bits to a computer or hardware and disable or interfere with it even in an EMS-hardened facility. It is conceivable that, in time, such could present the capability of penetrating cloud-based databases and other architectures thought to be secure.

Next, it is crucial the United States move forward with a financially viable and competitive 5G plan. The current US plan for 5G, that of using millimeter wave (mm Wave) technology in the high-band 5G spectrum, needs to be reevaluated due to its disproportionately high costs. China and the rest of the world are currently planning to use the mid-band 5G spectrum, especially sub 6Ghz, because of the significantly lower infrastructure requirements and attenuation problems that are associated with using the high-band spectrum. While it seems like a simple solution, the United States faces the challenge that both DOD and other USG entities are already utilizing the mid-band spectrum. Yet, to remain financially viable, both from a world standardization perspective and from an infrastructure deployment perspective, USG, DOD, companies, and academia must join together to either reallocate this mid-band spectrum or develop a way to share it.

One way to create this internal partnership is through incentives such as tax breaks, indemnification, or other measures. Another potential option is for these organizations to develop cheaper solutions using high-band, but as has been noted, this will create a disparity with the rest of the world. The Defense Innovation Board released a report in April 2019, "The 5G Ecosystem: Risks and Opportunities for DOD,"[28] which provides a more detailed assessment and recommendations. We will need USG and DOD to quickly and carefully review its ownership of mid-band spectrum to determine what should be kept, freed, and/or shared to maximize the effective use of the spectrum.

Education is the next key area requiring attention so 5G can be effectively and securely incorporated into society. As described previously, 5G is more than "just faster 4G." We need to overcome misunderstandings about 5G and help our nation understand 5G's benefits and vulnerabilities. Furthermore, as military base design and operations incorporate 5G, it will be important to plan for contingencies. Along with educating key military installation and operations planners, a broader DOD training plan should be implemented. Next, academia would benefit from instructing students on 5G's capabilities and then inviting students to explore the 5G trade space and technical opportunities in ways that could bring prestige and potential financial benefits to the institution. Likewise, corporations have a similar urgency to educate em-

28. USA. Department of Defense, Office of the Secretary of Defense. Defense Innovation Board. The 5G Ecosystem: Risks & Opportunities for DoD. By Milo Medin and Gilman Louie. Washington, DC: DOD, 2019. Available at https://media.defense.gov/2019/Apr/04/2002109654/-1/-1/0/DIB_5G_STUDY _04.04.19.PDF.

ployees on 5G's capabilities to highlight the potential unique, exclusive, and leading-edge uses of 5G. The USG could also partner to develop ad campaigns or videos to inculcate the public.

Such training should incorporate teaching about the potential threats to and from 5G. Also, informing the public of the interdependencies and risks associated with losing 5G would help raise this narrative to the forefront and drive action from policy makers. Finally, we would be wise to look at lessons learned from clubs, forums, and other parts of the country that engage in nongovernmental emergency preparations and then include these applicable lessons learned in the educational process throughout the whole of society.

The future is bright, and potential applications using the capabilities of 5G are bounded only by our own creativity. However, we must evaluate and act on the recommendations and actions provided to ensure uninterrupted access, financial viability, understanding, and resiliency across the 5G universe, which, like 4G did for 5G, lays the foundation for the 6G networks to follow.

QUESTION 4: What sustainable, efficient, and cost-effective approaches do we need to invest in/develop right now to keep Joint Force capability operational (viable) in a severe EMS-degraded environment?

Doctrine

The electromagnetic spectrum is a war-fighting domain. As US defense has increasingly relied on technology and as defense platforms and weapon systems increasingly rely upon the EMS, so have our adversaries and competitors increasingly challenged it. Consensus on this reality provides a common understanding and lexicon among the US government, military, allies, and civilian population. This consensus should also instill a culture of EMS awareness and unity across the nation, therefore setting the bedrock for future resource investment and doctrinal development that incorporates an appreciation for the EMS as a domain.

The development of a new EMS war-fighting doctrine cannot occur without broad awareness of EMS threats and opportunities. Unfortunately, many examples point to the USG's current lack of awareness of threats and opportunities in these areas.

Two recent examples were examined by EDTF. The first is a DOD request for information (RFI) for a small nuclear reactor to be used for forward operating bases,[29] and the second is a DHS request for proposal (RFP) for priority telecommunications services associated with the Cybersecurity and Infrastructure Security Agency (CISA) Emergency Communications Division (ECD). Assets developed by the private sector for these two governmental requests will be critical to future expeditionary and domestic DOD operations and future DHS emergency management services, yet neither request incorporated resilience to EMS threats.

Interestingly, such examples provide proof the US government is aware infrastructure resilience is needed but often lacks a complete understanding of how to develop or enhance it when seeking solutions. Consequently, the EDTF recommends that the originator of such RFIs amend them to include an additional objective: "Resilience to all natural and man-made hazards, including physical, cyber, and electromagnetic spectrum threats; tested to

29. RFI for Small Mobile Nuclear Reactor, Solicitation no. RFI-01182019-RD-WHS019, https://www.fbo.gov/index.php?s=opportunity&mode=form&tab=core&id=5f70e466e904a1b12748d6e04fcbaad4&_cview=0.

applicable military standards for IEMI and EMP survivability associated with nuclear weapons and command and control systems."

The DHS solicitation is for information technology and telecommunication services associated with the DHS's CISA ECD, which "collaborates with the public and private sectors to ensure the national security and emergency preparedness communications community has access to priority telecommunications and restoration services to ensure communication under ALL circumstances."[30] EDTF believes these circumstances include those associated with an EMS-degraded environment, specifically in the aftermath of a EMP attack. However, EDTF personnel were unable to find where this RFP requires EMS resilience.[31]

These examples illustrate the need for a targeted education program designed to alert civil servants and contracting officers at all levels (from federal to local) of the need for EMS resilience. Furthermore, EMS standards for new acquisitions should be made a requirement.

During discussions about doctrine, it was noted that during the Cold War the USAF would translate Soviet military doctrine and make such available to the military and universities. It is therefore also recommended this approach be reinstated to allow the United States and its allies to better understand the militarization of EMS. It was suggested that these be translated and made available at Air University's Curtis E. LeMay Center for Doctrine and Education. Members commented that they believe doctrine and policy are lacking in the area of EMP defense and that a doctrinal-level statement is likely the most critical starting point to normalize and unify EMP resiliency discussions.

Some efforts in the area of Air Force EMS doctrine have already begun. Recently the LeMay Center hosted an electromagnetic spectrum operations summit to update EW/EMS doctrine and draft an Air Force Annex 3-51 *Electronic Warfare* doctrine. As of this publication, Annex 3-51 is in final coordination. The LeMay Center is working to coordinate between AETC and the other major commands to develop standardized EMS academics for all Airmen. See appendix 2 for more information on the Enterprise Capability Collaboration Team (ECCT).

Additionally, research into the "golden hour" that is used in the medical community may be helpful in establishing doctrine or strategy for recovery operations. What is our golden hour after an EMP or GMD event? What does

30. Department of Homeland, Security Cybersecurity and Infrastructure Security Agency, Emergency Division, https://www.dhs.gov/oec-planning-and-preparedness-support.

31. RFP for Cybersecurity and Infrastructure ECD Priority Telecommunication Services, Solicitation no. 70RNPP19R00000004, https://www.fbo.gov/index.php?s=opportunity&mode=form&id=539562678ceb5c59b46d67a38ebaf53b&tab =core&_cview=0.

hour-one look like? There are critical systems that must be brought back on immediately after an event to enhance the chance of survival.

Contingency Planning, Training, Education, and Exercises

Beginning with the military-first approach discussed under 5G, we recommend all military members have EMS operations training and education. EMS vulnerabilities are present in every career field, and mitigation must be as understood as cyber hygiene. In addition to education and training, EMS objectives should be incorporated into all US exercises, war gaming, and primary, alternate, contingency, and emergency communications plans. Doing so will ensure a properly tested joint combined military and civilian strategy during catastrophic EMS degradation.

It is the strongest possible recommendation of the task force that mission-type orders and contingency plans be developed by US Northern Command (USNORTHCOM) to ensure the capabilities and assets at more than 300 military installations and defense properties in the CONUS can achieve coordination if communications are lost or disrupted for extended period.

One tenet of airpower that has not been stressed is centralized control and decentralized execution. The task force observes that over the last 25 years the US military has benefited from an overwhelming supremacy and has not had to exercise centralized control and decentralized execution. This is because the Joint Force has been operating in a permissive environment where real-time information and battlespace awareness are readily available. In an EMS-degraded environment, however, where communications are nonexistent or in short supply, decentralized control and decentralized execution will be a necessity so commanders can ensure decision continuity at the lowest level necessary for mission execution. Without standing mission-type orders from more than 300 military installations and countless other essential federal functions, there is a realistic prospect that a nationwide disruption to the power grid or telecommunications networks could degrade the ability of organizations and agencies to assist with recovery. Such conditions warrant EMS degradation be widely incorporated into exercises and war gaming.

However, before this is accomplished, it is the strongest possible recommendation of the task force that mission-type orders and contingency plans be developed by USNORTHCOM to ensure the capabilities and assets at more than 300 military installations and defense properties in the CONUS can achieve coordination if communications are lost or disrupted for extended periods. Without standing orders or instructions, commanders will be left guessing how to prioritize and position the disposition of available resources and assets. This must be remedied immediately and may be done at little to no cost.

Integration between USNORTHCOM, United States Strategic Command, and the DHS is necessary for sharing resources and knowledge to aid in the defense of the nation and to prepare for an EMS impact that could have widespread effects on the civilian population. As outlined previously, leadership may come from different agencies depending on the type of event, but prior design and coordination are essential.

Finally, to increase the effectiveness of education and training programs, creating an EMS "red team" is a prudent next step. Red teams would use adversary capabilities, doctrine, and thinking to train the force, conduct traveling DOD exercises, and participate in DOD and civic emergency response exercises. Participation in community exercises is a low-cost method for public outreach that is within the DOD's control and ensures continuing public education in EMS vulnerability mitigation. Similar programs exist across the DOD. For example, the USAF has an outreach program that develops briefings and seminars to ensure the safe integration of civilian and military air traffic.

Materiel

Today, many viable and creative options exist to solve anticipated communication disruptions, but the planning must start *now* and required equipment must be protected. During an EMS outage, alternative means for communications would be necessary until mobile networks can be restored. Recently, AETC tested a mesh network that allowed for drones to propagate signals over more than 5,000 square miles. Concepts such as this should be developed and deployed to high-density population centers and key strategic sites around the country as part of USNORTHCOM crisis and contingency planning efforts.

Meshed networks are a new technology that uses individual handsets as nodes to distribute data, which may allow for communication in remote areas and after an EMP attack or EMS degradation. More research is needed into software-defined/reconfigurable radios and laser-based communications, which may allow access in a contested environment. Other innovative ideas include the ability to quickly launch micro-sat systems that would temporarily serve as a communication network, functioning as a UHF/VHF repeater.

Other solutions discussed involved the use of cognitive electronic warfare and AI to instantaneously detect threats and protect networks and send mass alerts, similar to an Amber alert, so people have critical information upon which to base their decisions. Even a one- or two-minute warning will allow decision makers to react quicker and speed recovery. Because damage to the infrastructure can come from various sources, including terrestrial and space weather, it is essential to quickly recognize the source of a threat.

Communication assets may also be prepositioned in EMP-hardened facilities or containers as a means of potentially increasing survivability. As an example, at the mayoral level, a city in Wyoming built Faraday cages to store critical equipment such as generators and communications hardware. These storage facilities could be expanded for the military, to include allied and coalition countries.

A streamlined acquisition process is needed to quickly purchase and test new and innovative shielding designs and solutions. There are methods to make the solutions to this problem happen more quickly. This could be similar to the Air Force, Special Ops, and NATO acquisition-lite programs, AFWERx, SOFWERx, and the NATO Innovation Hub. Start-up companies might already have what is needed to meet military requirements—but may not have the wherewithal to navigate the military acquisitions construct. An acquisition-lite team could consist of a few members who can quickly test and certify small companies.

In addition, the government can require future critical assets be developed with EMP protection capabilities. The best way to accomplish this is to provide tax and other monetary incentives for building in resilience or backfitting equipment with EMS shielding according to standards set by the USG and scaled according to the vulnerability and criticality of the asset.

Micro-power grid systems are also recommended to ensure military installations are made less vulnerable by reducing reliance on the commercial power grid. These may be implemented according to a prioritized list for critical military installations and should be hardened for EMP and cyber. An example of an effective micro-grid design is being implemented by the Puerto Rico Electric Power Authority in the wake of Hurricane Maria.[32] The design will re-establish the electric grid by moving toward interconnected, decentralized regions able to independently generate electricity with an emphasis on solar energy, natural gas, and battery storage.

32. For more information, see Megan Kerins, "The Puerto Rico Renewable Micrgrid Toolkit: A Data-Driven Approach to Resilience," Rocky Mountain Institute, 21 Decemner 2018, https://rmi.org/the-puerto-rico-renewable-microgrid-toolkit-a-data-driven-approach-to-resilience/.

In terms of alternative forms of communications that might be available in an EMS-degraded environment, the task force examined several, including fiber optics, high-frequency (HF) radios, and laser communications. Unlike the wider electric power grid, fiber optic lines are not vulnerable to EMP. However, the fiber nodes that power fiber optic lines are vulnerable. Fiber lines with hardened nodes can ensure fast and reliable communication. But, without prior attention to design and resilience, these lines of communications will also be unreliable. On the other hand, HF experts believe that HF radio would likely be more reliable after an EMP, for example, due to the ionization of the atmosphere.

Amateur radio has been a cornerstone of redundant and emergency communications for decades. Many member-owned radio stations are built with EMP and power grid–down considerations in mind. ARRL volunteer members have experience and awareness of space weather effects and emergency communications. Additionally, the military has a long-standing relationship with the HAM radio community through the Military Auxiliary Radio System (MARS, https://www.mars.af.mil/, http://www.marsradioglobal.us/). EDTF recommends inviting American Radio Relay League (ARRL) and MARS representatives to future EDTF discussions. Finally, any new comprehensive plans must examine how to ensure continued propagation of the timing signal, whether from GPS (space) or terrestrial sources. These plans and policies should also address prioritization and restoration actions. For example, first responders must have communications restored before basic users do, as should priority locations like Washington, DC, to ensure continuity of government.

Leadership

In terms of leadership, EDTF recommends that a strategic messaging policy for the United States with respect to EMS be developed and communicated. In general, the US should message that any attack with a HEMP is an act of war and a crime against humanity..

Leaders need to understand the threat of EMS, advocate for resourcing and governance, and provide focus. This will require organizations to take ownership of their assets and not rely on top-down direction to undertake mitigation efforts. The whole-of-government methodology, to date, has allowed responsibility to be shifted and even set aside until someone else made a decision. In many cases, a decision simply never happened. Because EMS attacks have the potential to affect the population as a whole, whether through transportation, communications, or basic necessities, it is important to have a single focal point for advocacy within government, individual or organization, be an advocate for EMS protection across the whole of government. However, in the interim, organizations must begin to own this issue individually.

Finally, in terms of leadership, EDTF recommends that a strategic messaging policy for the United States with respect to EMS be developed and communicated. In general, the US should message that any attack with a HEMP is an act of war and a crime against humanity. This messaging is necessary to help deter able actors who believe a HEMP is not considered an act of war against the United States.

Personnel

A critical piece of enhancing EMS resilience is the accessions of personnel (including military, civilian, and contractors) who have the right skill sets, aptitude, and desire to address EMS risks. This issue was discussed widely—the US is losing (or has lost) its corporate knowledge regarding EMS. Moreover, the nation is failing to recruit the best talent. Some potential accessions options to "join the cause" within the DOD should include defining future challenges and then attracting those interested in solving those challenges.

Facilities

To minimize the effect of an EMS attack, DOD buildings and critical infrastructure need to be hardened. This must be accomplished through a hardening plan prioritizing critical assets due to the cost associated with hardening assets that are already built. New military construction plans and standards should be reviewed to determine which buildings to harden, because it is more cost effective to incorporate hardening standards into new construction than into existing structures. Incorporating EMP shielding, for example, in new construction is believed to only increase the cost of construction by five percent of the total capital costs.

Conclusion

The United States and NATO are at an unprecedented strategic crossroad. It is a crossroad because bold decisions must be made about commanding outcomes that will soon reshape the international environment. It is unprecedented because there has never been a time in history when all domains (space, air, land, sea, and cyber) and nearly all activities within them, both civil and military, have merged and become principally controlled by a single powerful overarching domain—the electromagnetic domain.

The inconceivable is no longer a distant inspiration, it is on our doorstep. We are, in many ways, experiencing a transformation from science fiction to science fact where technologies have begun to comparably behave and evolve like living organisms. Technologies are forming, splitting, merging, mutating, and even becoming intelligent. In this environment, it is plausible that as our understanding of the electromagnetic spectrum fuses with quantum physics, the communications architectures of today, which consist of transmitters, receivers, and networks, will no longer be required to move information and data across space and time.

Our pursuit of understanding and the implications of these new realities must be driven by compassion and a desire to improve the human condition. However, such knowledge must also be informed by a candid and intelligent understanding that human nature does not change. Thus, with new discoveries, there will be new risks. Such risks will require us to advance beyond reactive strategies to develop proactive strategies that invest in promising opportunities and help guide new sciences and technologies such as 5G, 6G, quantum communications, and even risky embryonic ideas not yet known to the world.

However, despite our rapid advancement into the digital and information ages, we continue to pull against a tremendous inertia derived from our first understanding of the electromagnetic environment, an environment that extends to the very boundaries of our universe and which permeates all forms of life and physical matter. The electromagnetic domain envelops us so entirely we usually take its existence lightly. Yet, the electromagnetic domain is, in every way, connected to everything else. The electromagnetic spectrum works in and through all we do.

Frequently ignored, sometimes minimized, commonly misunderstood, and many times at the edge of our deliberation, where the electromagnetic domain is concerned, what is often the last thought must become a forethought as we look to shape the future to ensure our freedom and maintain power over tyranny. The electromagnetic domain will become the dominant and controlling feature in how modern nations and their defense elements engage in competition and strife. Even if unseen, the nefarious manipulation of this domain below the threshold of war is being used to aggress and often harm the US, its allies, and the public.

Once there is a recognition of the complexities present within the electromagnetic domain and a demonstrated willingness to lead, we must educate and teach our communities about the challenges and opportunities in this environment. Without pooling the intellectual capital of the wider force and collaboration with our allies, industry, academia, and civic organizations and citizens, the critical mass needed for substantive change will not likely materialize. Therefore, efforts like the Electromagnetic Defense Task Force (EDTF) must be cultivated, supported, and replicated.

The EDTF is not a panacea for dated doctrine, a fix for decision paralysis, a corrective for stagnant acquisitions, or even a wake-up call to the government and public. This effort could not be so ambitious. However, the ideas and information within this report are offered with sobriety and candor to credibly inform the deepest conversations and deliberations of our age.

As a stakeholder in our future, whether senior leader or senior citizen, junior officer or student, you are vitally important to the successful shaping of our future and the future of the electromagnetic domain. As we prepare this future, we must not be held captive by uncertainty or fear of the unknown, but rather take hold of the opportunities in front of us. If we comprehend the shape of what can be and work together, we can sculpt the future for the benefit of all humanity. Such vision requires, first and foremost, leadership that recognizes when the environment has changed, even against seemingly impossible odds. Like the young British officers discussed in the introduction to this report, we can use all within our reach to ensure successful outcomes. But we must act.

The opportunities now demand we think to win, and such thinking requires us to consider everything. If we fail in this regard, we will have failed cognitively. We can avoid a future where the US and its allies are humbled by an adversary who imagined better—whose ideas were unbounded and whose determination and audacity we failed to match. We are in a contest of imaginations, and those who imagine best, and follow next with actions, will shape things to come.

If we remain on our present course, the terrain may seem familiar, but adversaries will take the initiative. Given the ubiquity of the electromagnetic spectrum, this future outcome is and must be unthinkable.

Imagine an actor who decides to dominate space, the ultimate high ground, not for peaceful purposes but for ambition and conquest. Imagine, space assets stationed above all humanity controlled by unthinkable tyranny. Imagine, dominance or terrorism from space platforms capable of projecting directed energy on cities, communities, and towns. Imagine the widespread disruption of communications or the use of electromagnetic systems to lock out positioning, navigation, and timing (PNT or GPS). What we do next will shape the ability of the US and our allies to prevent such futures.

We are in an electromagnetic age, and we must be ready to articulate a vision for how to preserve lasting peace, the rules-based order, the sanctity of life, our sacred liberty, and the pursuit of happiness.

As we demonstrate courage, leadership, and a willingness to learn and compete with novel ideas, there must be a demand for accountability in the critical areas that sustain our national welfare. Such accountability requires uniform standards, rigorous physical component testing, and incentives for manufacturers and customers to both demand and integrate electromagnetic spectrum (EMS) resilience into new and existing systems and designs. For example, estimates for end-to-end electromagnetic pulse (EMP) hardening of the US power grid and critical infrastructure range from $5 billion to $50 billion, and while it is recognized that an ideal outcome would be the complete protection of the nation's infrastructure, resource constraints make this outcome unlikely. Yet, the use of military standards to harden nuclear power stations, for example, is a justifiable investment from a risk and security standpoint. Where such improvements cannot be made, the US and its allies must find intelligent, low-cost, and practical solutions that enhance resilience in peace and in times of conflict.

We are in an electromagnetic age, and we must be ready to articulate a vision for how to preserve lasting peace, the rules-based order, the sanctity of life, our sacred liberty, and the pursuit of happiness. Part of this communication is an ability to inform future actors about the position of the United States of America with respect to EMS threats. The employment of such strategic means, including EMP, the disruption of PNT/GPS, and the employment of EMS activities against terrestrial or space-based targets, must be considered an act of aggression and, in some cases, a crime against humanity.

Communications with the public about the wider risks of EMS, EMP, geomagnetic disturbance (GMD), and other emergent risks is an essential component in maintaining the trust and confidence of the American people. As this trust is enhanced, the Department of Defense (DOD) and other agencies should, as much as practical, declassify and release information that can help facilitate broader knowledge on the issues, assist in the development of better EMS technologies, and promote accountability. Without a sound knowledge of the facts, the American people are at a disadvantage. In an effort to lead by example, the EDTF has ensured this report is releasable to the public and encourages the widest possible dissemination.

Another low-cost measure is promoting public awareness of the limitations of the DOD and government in an EMS-degraded environment. Under certain conditions, strategic threats may be presented that bypass traditional deterrence schemes. Such threats may emerge from gray zone areas and rapidly deploy to create widespread outages and disruptions. However, similar effects of GMD may arise that interact with Earth's magnetic field to cause similar disruptions. By guiding the public to an accurate and realistic understanding of the EMS environment, the public will be served by (1) enhanced household and community resilience, (2) increased support for government measures and strategies that can further ensure the US and its allies are prepared to mitigate challenges, and (3) improved government transparency.

It is the strongest recommendation of this task force that USNORTHCOM develop concepts of operations and contingency plans for major EMS impacts (including EMP, GMD, and space-based PNT/GPS degradation) to the lower contiguous 48 states. Such plans may be built for little to no cost. However, the degree to which the resilience of the United States and Joint Force will be enhanced by this straightforward strategy cannot be overstated. Providing unified direction to the disposition of the US-based Joint Force will allow, in the unlikely event of a crisis, an organized and prioritized response that builds toward capability and speeds recovery.

At the nexus of technology, strategy, and our national power is an electromagnetic domain that is allowing our world and society to be resculpted. If we hold fast to that which shaped our first understanding, the grand design of what is to come will be crafted without the benefit of our value system. As sweeping changes occur, it is up to our nation's leaders and visionaries to form an image of what should come. The future will not answer to our wants, desires, or beliefs. The future will respond to our will and the intelligent steps we take to shape it.

We must consider the course to choose at this strategic crossroad. We can maintain the status quo by affirming our existing understanding of the environment and be faced with the prospect of conforming to a system designed for us by our adversaries and peer competitors. We can make modest improvements to our existing infrastructure and pursue incremental gains by incorporating better standards with physical testing and validation. Or the United States can transcend many of the most challenging aspects of the electromagnetic domain by redesigning the US critical infrastructure in such a way that every community, family, and home has access to uninterruptible energy, data, and communications from a resilient architecture.

While the gears of progress have turned and advanced with our understanding of the electromagnetic spectrum, such progress can be crippled if we fail to grasp its incredible potential to help humanity on its journey forward. Thus, the electromagnetic domain must be understood, shaped, and positioned as a dominant enabling force for the defense and health of our nation and society.

How to accomplish this positioning is nothing short of a fantastic problem. If we are guided by a willingness to learn, lead, and understand fresh opportunities, we may advance our thinking, reshape our paradigms, and preserve and enhance our way of life.

These are times like no other. The task force thanks you for your interest, consideration, and ongoing support.

Selected Resources

The following are helpful resources on electromagnetic pulse (EMP).

Resource 1: Executive Order 13865. *Coordinating National Resilience to Electromagnetic Pulses*, 26 March 2019, https://www.govinfo.gov/app/details/DCPD-201900176.

This executive order implements core recommendations of the Congressional EMP Commission on an accelerated basis. It combines cybersecurity and security against electromagnetic spectrum threats, building upon executive branch orders and actions from previous presidential administrations to address threats from solar weather. Further, it requires that "the Federal Government must foster sustainable, efficient, and cost-effective approaches to improving the nation's resilience to the effects of EMPs."

The order states that the assistant to the president for National Security Affairs, working with the National Security Council and the director of the Office of Science and Technology Policy, "shall coordinate the development and implementation of executive branch actions to assess, prioritize, and manage the risks of EMPs."

It directs the secretary of the Department of Homeland Security (DHS) to coordinate with the Energy and Defense secretaries, other agencies, and the private sector to "develop a plan to mitigate the effects of EMPs on the vulnerable priority-critical infrastructures."

Since there is not a substitute for EMP testing of equipment, one critical feature of the executive order is its requirement that the vulnerability of essential, critical infrastructure equipment is established through empirical testing by an EMP simulator rather than computer modeling.

Table 1. Important deadlines specified in Executive Order 13865

Date	Government agency leads	Required actions summary	Secs.
26 Jun 2019	Sec. Homeland Security, SSA, and other agencies	List National Critical Functions and Critical Infrastructure Systems/Networks/Assets that, if disrupted, have catastrophic effects. Update as necessary.	6(a)(i)
26 Sep 2019	Sec. Homeland Security	Review test data and identify any gaps in test data regarding effects of critical infrastructure systems, networks.	6(b)(i)
26 Sep 2019	Sec. Homeland Security	Use the sector partnership structure to develop an integrated cross-sector plan to address identified gaps. Implement the plan in collaboration with the private sector as appropriate	6(b)(ii)

26 Sep 2019	Sec. Homeland Security	Develop and implement pilot test to evaluate engineering approaches to mitigate EMP impacts on the most vulnerable critical infrastructure systems, identified in 6 (a)(ii).	6(c)(ii)
26 Sep 2019	Sec. Homeland Security, through administrator of FEMA	Review and update federal response plans, programs, and procedures to account for the effects of EMPs.	6(e)(i)
26 Dec 2019	Sec. Homeland Security (with Sec. Defense and Sec. Energy)	Develop plan to mitigate effects of EMP on critical infrastructure systems/networks/assets. Implement plan consistent with DHS. Update plan as required by results derived from in 6(b) and 6(c).	6(d)(i)
26 Mar 2020	Sec. Homeland Security (with Sec. Defense and Sec. Energy)	Develop risk assessment on EMP, and then develop quadrennial risks assessment.	5(f)(vii)
26 Mar 2020	Sec. Energy	Review existing standards for EMPs. Develop or update quantitative benchmarks that describe physical characteristics of EMP that are useful and can be shared by owners and operators of critical infrastructure.	6(b)(iii)
26 Mar 2020	Sec. Energy	Identify regulatory and nonregulatory mechanism, including cost recovery, that can enhance private-sector EMP efforts.	6(c)(iii)
26 Mar 2020	Agencies supporting national essential functions (NEF)	NEF agencies shall update their operational plans to prepare for, protect against, and mitigate the effects of EMPs.	6(e)(ii)
26 Mar 2020 and then every 2 years	Sec. Homeland Security (with Sec. Defense and Sec. Energy)	Submit report to the president of the United States (POTUS) analyzing tech options to improve resilience to effects of EMP, and identify gaps in available technological and identify future R&D opportunities.	6(c)(i)
26 Jun 2020	All agencies supporting NEFs	Update EMP plans in terms of vulnerability.	6(a)(ii)
26 Jun 2020	Sec. Homeland Security	Identify which critical infrastructure systems/networks/assets are most vulnerable to EMPs effects.	6(a)(ii)
26 Sep 2020	Sec. Defense (with Sec. Homeland Security and Sec. Energy)	Conduct pilot test to evaluate engineering approaches to harden strategic military installation and supporting infrastructure against EMPs.	6(d)(ii)
26 Dec 2020	Sec. Homeland Security	Provide to POTUS Staff assessment of EMP effect on communication infrastructure, and recommend changes to operational plans for response and recovery after EMP event.	6(e)(iii)
26 Mar 2021	Sec. Defense	Report cost and effectiveness of 6d(ii) test to POTUS.	6(d)(iii)

26 Jun 2021	Sec. Homeland Security	Develop plan to address EMP Effect Test Data gaps.	6(b)(ii)
26 Mar 2023	Sec. Interior	Complete in four years magnetotelluric survey of contiguous US to help critical infrastructure owners and operators to conduct EMP vulnerability assessments.	6 (b)(iv)

Resource 2: National Coordinating Center for Communications (NCC). *Electromagnetic Pulse (EMP) Protection and Resilience Guidelines for Critical Infrastructure and Equipment,* 5 February 2019, https://www.dhs.gov/.

The DHS's NCC has been working on this information product for at least four years, having published its first version in 2016 and updated it in 2019.

This document provides guidelines to assist federal, state, and local officials and critical infrastructure owners and operators to protect mission essential equipment against EMP threats. It was created to help fulfill the Secretary of Homeland Security's responsibilities to:

- "Provide strategic guidance, promote a national unity of effort, and coordinate the overall Federal effort to promote the security and resilience of the nation's critical infrastructure." [*Presidential Policy Directive 21 - Critical Infrastructure Security and Resilience*]
- "Ensure . . . the necessary combination of hardness, redundancy . . . to obtain, to the maximum extent practicable, the survivability of NS/EP {national security/emergency preparedness} communications" [Executive Order 13618, *Assignment of National Security and Emergency Preparedness Communications Functions*]
- "Be the focal point within the Federal Government for all EMP technical data and studies concerning telecommunications." [Title 47 Part 215 of the Code of Federal Regulations (CFR)]"

The document also responds to the US Congressional EMP Commission's recommendation that the "Department of Homeland Security should play a leading role in spreading knowledge of the nature of prudent mitigation preparations for EMP attack to mitigate its consequences."

The document establishes four EMP protection levels "initially developed at the request of the federal Continuity Communications Managers Group but are applicable to any organization that desires to protect its electronics and critical infrastructures."

"In addition to making recommendations on how to physically protect electronic equipment from different types of EMP, this document provides guidance on how to help ensure communications and information systems (and their supported missions) can continue to function or be rapidly restored after one or more EMP events. Hence, Appendix C contains information on priority service programs (like Government Emergency Telecommunications Service, Wireless Priority Service, and Telecommunications Service Priority) as well as on the SHARES alternate communications service that can be used to support critical missions and to facilitate and coordinate restoration activities. The document supports the concepts of resiliency and recovery. The intention is to provide different levels of protection that should allow less damage and/or loss of data as one moves to a higher level of protection. This also should result in shorter outages of the system mission."

The DHS NCC specifies that "these guidelines do not endorse any referenced product, company, service, or information external to DHS" and that "The audience for this document is all governmental and civilian officials and owners and operators of critical infrastructures, particularly those using sensitive electronics for their operations. This includes the 16 critical infrastructure sectors identified under 'Presidential Policy Directive 21 (PPD21): Critical Infrastructure Security and Resilience.' "

Resource 3: Air University Library Research Guide on EMP, http://fairchild-mil.libguides.com/Electronic_Warfare.

This collection includes Air University research, books, documents, journals, articles, databases, websites, and electronic resources selected by Air University Library research librarians.

Appendix 1

Electromagnetic Pulse (EMP) Impacts on Nuclear Power Plants and the Role of the Nuclear Regulatory Commission (NRC)

In 2018, the Electromagnetic Defense Task Force (EDTF) identified potentially major concerns relating to the safety of US nuclear power stations in the event of an EMP. In particular, two primary issues were raised: The first was the sparsity of literature addressing the topic of how an EMP may interact with nuclear power stations, and the second was the total absence of any physical testing data to validate the assumptions made by the few studies on the subject.

In the NRC's parlance, an EMP is a "beyond-design-basis event" (BDBE) that does not have to be taken into account in facility design or be protected against with the use of "safety-grade" systems, structures, and components. Thus, no nuclear power plant was specifically designed to survive an EMP event. The key question in assessing the vulnerability of nuclear power plants to EMP is to what extent an EMP could cause damage both to nuclear plant systems and to the surrounding infrastructure and whether that damage would exceed that which the plant, its personnel, and its support systems are currently required to withstand or mitigate.

The primary impact of an EMP on a nuclear power plant would be a loss of off-site power due to failure of the grid. Such an event is a design-basis accident, and nuclear power plants are required to have safety-grade emergency diesel generators (EDG) to ensure that adequate cooling of the reactor fuel is maintained.

Nuclear plants are also required to cope with the possible failure of the EDGs, an event known as a station blackout. Station blackouts are considered BDBEs. Prior to the 2011 Fukushima accident, nuclear plants were only required to cope with a station blackout for a relatively short time, typically four to eight hours, based on estimates of how long it would take to restore access to power from the grid. However, after Fukushima, which suffered a station blackout for 10 days, the NRC required nuclear plants to prepare to cope with a loss of AC power indefinitely in the event of a beyond-design-basis external event (BDBEE; e.g., a natural disaster).

Nuclear plants have complied with the NRC's post-Fukushima requirements by procuring and staging portable emergency equipment, such as diesel-powered pumps and EDGs, that could be used to ensure reactor and spent fuel pool cooling in the event of a long-term blackout. This strategy is called

FLEX. FLEX equipment does not have to meet the same standards as safety-grade equipment to protect against design-basis events, but only must be "reasonably protected" against external hazards. The FLEX strategy also includes two national response centers, one each in Memphis and Phoenix, that would be able to supply additional sets of FLEX equipment to up to four reactors in distress. Nuclear plant owners are required to make arrangements with commercial companies to provide transport of replacement FLEX equipment from the national response centers, as well as to provide additional diesel fuel supplies to power the equipment.

Therefore, the threat posed by EMP to nuclear plants depends on how such an event could challenge the strategies currently in place to deal with electrical system disturbances, from loss of off-site power to indefinite station blackout. Key considerations are whether the safety-related EDGs and/or electrical distribution systems would be disabled, whether FLEX equipment would remain functional and FLEX strategies executable, and whether supply of diesel fuel and replacement equipment would be disrupted by a large-scale high-altitude electromagnetic pulse (HEMP) event. The NRC has not done such an analysis. These potential gaps need to be fully analyzed to better assess the current vulnerabilities of nuclear plants to EMP.

One major deficiency of the FLEX strategy is the absence of any NRC requirements for training, drills and exercises, staffing, and communications related to their implementation. While the NRC approved the inclusion of such requirements in its draft final rule on mitigation of BDBEs in 2016, in January 2019 the current commission voted to strike all such requirements from the final rule.

Although nuclear plants are required to conduct training to safely handle design-basis natural and man-made catastrophes, BDBEs such as extended station blackouts fall outside of these planning and training scenarios. This does not mean that such events cannot be mitigated; it just means, from a definition and design risk standpoint, operators and staff are not trained, do not exercise, do not plan, or do not have facilities and hardware intentionally designed to withstand such events. Any ability to address electromagnetic spectrum (EMS) or EMP concerns would require on-the-spot innovation, ad-hoc procedures, and whatever equipment remained functional.

To address these concerns in a comprehensive and transparent manner, EDTF hosted members of the US NRC with EDTF Fellows from more than a dozen organizations and labs with experience in electromagnetics and nuclear power and power generation. Also present were members of the White House Staff, Office of the Secretary of Defense, Joint Staff, Idaho National Labs, Sandia National Labs, Union of Concerned Scientists, and a number of scientists and electrical and nuclear engineers. In total, 29 participants took part in three meetings over two days. One meeting was conducted at the unclassified level and two were conducted at the classified level. The meetings were organized and moderated by Maj David Stuckenberg and led by Lt Gen Steven Kwast and Brig Gen David Gaedecke.

Classified discussions raised a number of issues that will not be discussed in this paper. Further information on these meetings is available by briefing and may be requested by appropriate agencies.

In the paragraphs that follow, the major discussion points regarding nuclear power plant safety in relation to EMP will be discussed. It should be noted that the EDTF appreciates the spirit of cooperation, collaboration, and goodwill demonstrated in the lead-up to and during the meetings. The EDTF also acknowledges the mutual goal of the EDTF and NRC to faithfully ensure all stakeholders and the public are well informed on these technical issues and unknowns. Notwithstanding, there was both consensus and a lack of consensus on a variety of points summarized below.

EDTF-NRC Discussion Areas

Italicized text signifies agreement.

Area 1. Lack of credible research on EMP impacts to nuclear power stations.

EDTF position: Other than the 1983 report from Sandia National Labs, no credible research has been done on this issue. The Sandia study is faulty on more than a dozen assumptions and was not well received even within the nuclear power community at the time it was released.

NRC position: The 1983 study was not the only report done to study EMP impacts. Another study was conducted in 2009, which validated the first.

Recommended action: Since no comprehensive testing has been conducted at an operating or recently closed power station, modeling assumptions, irrespective of literature source, are not reliable. Many EMP tests conducted on actual equipment show modeling can be wrong by orders of magnitude. Suggest actual physical testing.

Area 2. Lack of comprehensive physical facility testing.

EDTF position: This means that how a nuclear power station will react to EMP as a complete system is largely a total unknown.

NRC position: NRC has tested the nuclear power stations with accurate computer-based simulations.

Recommended action: Since no actual testing has been conducted, such assumptions are gravely imprudent. EMP tests conducted on actual equipment show that modeling can be wrong by orders of magnitude. Suggest actual physical testing.

Area 3. ***EMP is by definition a BDBE.***

EDTF position: *This means, with limited exceptions, that no staff or operators are required to be trained in how to react or mitigate unanticipated and unforeseen impacts.* Thus, present guidelines for responding to certain beyond-design-basis actions are not required by the NRC, but are done on a voluntary basis by licensees (and therefore not subject to NRC enforcement actions).

NRC position: *NRC agrees.*

Recommended action: *Detailed guidelines should be developed both on a plant-wide and nationwide level to address mitigation of potential EMP effects, and periodic training should be conducted among all parties involved in the response.*

Area 4. EMP will cause a prolonged station blackout (loss of off-site power and on-site EDG and/or electrical distribution systems). This issue area is linked with issue area 6.

EDTF position: All electronic devices are subject to impact and disablement by an EMP where there is sufficient field strength.

NRC position: Sufficient backup systems will maintain/allow: safe shutdown, core cooling, and spent fuel cooling. These are also the NRC's safety priorities.

Recommended action: These cannot be guaranteed due to a lack of actual testing. NRC suggests EDG will work and that fuel will be available from off-site in the event of a long-term blackout. However, NRC admits that without these logistical provisions there are no guarantees. There is an apparent contradiction in planning as the NRC admits that fuel delivery, for example, cannot be guaranteed, but it still relies on such deliveries for plant safety.

Area 5. EMP may impact control rooms and sensitive electronics.

EDTF position: All electronic devices are subject to impact and disablement by an EMP where there is sufficient field strength.

NRC position: NRC does not anticipate significant penetration of EMP fields into a nuclear power station due to design of the structures.

Recommended action: Since no actual testing has been conducted, such assumptions are imprudent. EMP tests conducted on actual equipment show that modeling can be wrong by orders of magnitude. Suggest actual physical testing. USAF nuclear command and control facilities and missile silos are often underground and even covered by tens of feet of concrete and metal rebar. This does not negate the need for EMP hardening. Such facilities are hardened to careful military specifications.

Area 6. Post-shutdown EDGs may not function. This issue area is linked with issue area 4.

EDTF position: EDGs have circuitry that can be impacted and incapacitated by an EMP, especially their control systems. They may not be reliable unless hardened to military standards.

NRC position: EDGs are normally disconnected from safety-related systems, this should protect them from induced EMP currents.

Recommended action: Consideration has not been made for secondary attacks. This means that any surviving generators, once connected and providing backup power, may be subsequently impacted. Moreover, even unpowered and unconnected devices can fail from EMP, as was demonstrated in Soviet HEMP tests over Kazakhstan in 1962, where backup generators were later found to be damaged. Recommend NRC investigate control circuit board bypass options with which to backfit EDGs to ensure manual operation is possible in post-EMP conditions.

For example, EDG modules are available which allow the bypassing of complex microcircuits. Recommend all station operators be required to maintain an ability or "kit" to bypass circuits to ensure an ability to operate EDGs in manual mode.

Area 7. *Post-EMP logistics to the nuclear power station, including diesel, would be exhausted after one week (seven days).*

EDTF position: *This means that the EDGs that would continue supplying electricity to the spent fuel pools and other vital components could stop if there is no way to replenish fuel.*

NRC position: *Assurance of core and fuel spent fuel pool cooling in a long-term power grid outage is needed.*

Recommended action: *EDTF suggests evaluating the viability of immediately providing both EMP-hardened EDGs and at least six months of diesel fuel at each site. EDTF also suggests rapid exploration of technological solutions such as the application of long-term EMP-resilient power generation assets to power cooling systems. Such could include technical evaluation of Rankine or Brayton Cycle technologies, solar photovoltaic systems, and thermoelectric generators that can use heat from the spent fuel pool to generate power.*

Area 8. Post EMP, spent fuel pools may not have adequate electrical power to the cooling pumps.

EDTF position: See above/below.

NRC position: See above/below.

Recommended action: See above/below.

Area 9. Before an EMP or station blackout, it might make sense to have more spent fuel in dry cask storage in order to reduce the risk of a self-sustaining zirconium fire in the spent fuel pool in the event of an extended loss of cooling.

EDTF position: Expedited transfer of spent fuel to dry cask storage can significantly reduce risks posed by potential loss of cooling to spent fuel pools. (Reference 2018 EDTF report for tables and figures.)

NRC position: While the NRC expects spent fuel pools would boil off in days or weeks without electrical power for cooling, they do not expect EDG failures. Post-Fukushima safety improvements include instrumentation of spent fuel pools. Potential inability to obtain fuel delivery is a concern. Suggest the Department of Defense (DOD) provide a logistics option/guarantee.

Recommended action: The imperative remains to move as much spent fuel into dry cask storage as practical. Spent fuel can be transferred to dry storage after about five years of cooling. By moving more fuel out of the pool, if the pool does lose power and boils off, the likelihood of a pool fire decreases and there will be less material to cause radioactive release (for more information on this area reference the 2018 EDTF report). This is a passive safety measure. EDTF recommends that the NRC does not rely on DOD for logistics support in the event of a severe EMP event.

Area 10. ***Nuclear power plant physical security was not addressed in 2018 but was addressed in 2019.***

EDTF position: *There is currently no plan to extend or support security personnel in a prolonged station blackout.*

NRC position: *NRC agrees.*

Recommended action: *Part of a holistic plan for EMP issues should include how to support staff that will not receive immediate relief due to potential off-site impacts to food, water, transportation, communications, etc. During the Fukushima disaster, this issue created many concerns. EDTF strongly recommends that NRC create the conditions whereby nuclear plant owners/operators can provide both access and resources to care for the immediate families of nuclear power station personnel during a blackout.* Moreover, the question must be posed as to whether nuclear plants in a post-EMP weakened state would become targets of opportunity for terrorists/extremists, and whether it is appropriate to consider provisions for addressing this increased threat. State and local law enforcement, FBI, etc., may be limited in the ability to provide an effective response under post-HEMP conditions. Also, the impact of EMP on digital systems important for security—alarms, access authorization, assessment tools, communications—may not have been fully evaluated.

Area 11. Component hardening standards were not addressed in 2018 but were addressed in 2019.

EDTF position: No US nuclear power station is hardened to military standards. It makes sense that if the DOD would harden nuclear assets with known standards the NRC would require the same.

NRC position: Agree NRC does not harden to DOD or military standards. However, some nuclear power station features do meet military standards by design.

Recommended action: The EDTF questions these assertions. The safety of a nuclear power station must be absolute in order to maintain the public trust. As a confidence-building measure, a physical testing baseline should be established from which inferences and modeling can be done. It also seems reasonable that NRC licensees would be required to harden to military standards given the risks posed to nuclear power sites. Recommend the NRC consider requiring military-standard EMP hardening of facilities or proof of equivalency for individual sites.

Area 12. Site security and small EMP attacks were not addressed in 2018 but were addressed in 2019.

EDTF position: HEMP is a large-scale attack that may arise of state or nonstate actions. However, there are additional concerns that smaller vehicle-borne EMS devices (which have been created) could affect a nuclear power station by simply directing energy toward critical facility nodes.

NRC position: It is believed that such impacts would be negligible due to the attenuation of signals by the physical structure. In addition, modeling for EMP indicated there will be practically no impact to safety systems.

Recommended action: This issue is significant and un-mitigated. Modeling does not adequately establish reliable information without at least a physical testing baseline. To date no nuclear power facilities have been subjected to an actual EMP field to establish a baseline.

Area 13. Ability to safely conduct a shutdown in the event of an EMP blackout.

EDTF position: A station shut down by an EMP is a station suffering from a BDBEE. Such means training may not address any particularities arising out of unexpected circumstances associated with EMS effects.

NRC position: While EMP is a BDBE, stations are expected to shut down correctly and orderly. There are no digital components connected to equipment required for shutdown; most nuclear station control systems are still analog.

Recommended action: Lack of physical testing leaves many questions about what may or may not work in a shutdown. During the accident at Three Mile Island, an incorrect reading of a valve position on a digital readout caused an inadvertent release of radiation. Recommendation is to harden facilities to DOD EMP standards.

Area 14. Efforts under way to digitize most plant controls were not addressed in 2018 but were addressed in 2019.

EDTF position: There is concern that digital components will fail if subjected to EMP field strength above 8kV per meter.

NRC position: There is a strong campaign to digitize plant control room electronics. However, approval is slow and the process is expensive. When approval is made the NRC attempts to evaluate second- and third-order effects.

Recommended action: Digital components being installed in nuclear power stations have not been subjected to EMP testing. However, most Chinese nuclear power stations and many Russian facilities have tested components. The apparent disparities continue to be a concern.

Area 15. The ability to maintain FLEX facilities for power station supply/ reach back.

EDTF position: Delivery of FLEX assets will likely be unreliable due to failures in logistics and supply chains for reasons ranging from potential loss of satellite positioning, navigation, and timing (PNT) to inability to fuel trucks, to choked highways/transportation infrastructure due to immobilized autos, to societal chaos.

NRC position: FLEX assets are now maintained on several sites in separate storage facilities. These facilities are not EMP hardened nor is delivery assured. For example, FLEX strategies often involve the use of solid-state battery chargers and inverters that could be affected by EMP.

Recommended action: Consideration should be given to advancing the FLEX program to provide more regional depositories (beyond AZ and TN warehouses) and creating EMP-hardened structures for spare EDGs. Many structures may now be hardened with aftermarket materials at a low cost. More information is available through the Air Force Research Laboratory.

Area 16. Issues impacting the public health and military assets downwind from power stations. The important question here is whether occupationally significant doses of released radiation could affect downwind DOD facilities, triggering either protective actions (see, e.g., the repositioning of US naval vessels after Fukushima when low levels of radiation were detected) or requiring personnel to be exposed to needless radiation exposure to carry out essential duties. This could result both from passage of the initial plume from core melt and from long-term land contamination by cesium-137 from both core melt and spent fuel pool fires.

EDTF position: Psychological issue. These stations are the "crown jewel" of the US infrastructure. The DOD has no plan for impacts to personnel and equipment issues in this area. However, there could be major impact if planning is not conducted.

NRC position: Modeling indicates there will be no early radiation dose fatalities far from the plant [distance not specified; modeling not provided].

Recommended action: More information is needed to determine if the extended plume release (beyond 10 miles) will impact the public and military assets and personnel. The potential release of radiation can trigger panic. More information is needed to inform military planners on how to prepare for contingencies.

Area 17. What are the assumptions for the restoration of off-site power to the facility? Current diesel fuel storage for EDGs only require one week (seven days) of fuel.

EDTF position: It could take between weeks and months to restore on-site power and restart the power station. This is in part due to long replacement times for assets such as power transformers that, according to EMP experts, will likely fail from an EMP or geomagnetic disturbance (GMD) and also due to the need for the external grid to be ready to accommodate the load.

NRC position: Currently the NRC does not require stations to maintain fuel beyond one week (seven days). Additionally, the NRC does not require security beyond that which is reasonable for a contractor security company. The NRC does not consider state-level threats or intentional acts to be within the scope of its mitigation schema.

Recommended action: Within the wider US critical infrastructure nuclear power stations are the crown jewel. The NRC should consider measures to achieve mitigation that considers both state and nonstate actors in the security of facilities. In addition, planning is not conservative as assumptions for restoration of off-site power—which is essential to spent fuel pool cooling—may take months to restore. This issue continues to pose a substantial risk to the public and DOD assets. While off-site power is not the responsibility of the NRC, the NRC should plan to success, not failure. By failing to close the loop with Federal Energy Regulatory Commission on where transformers would be sourced and how long they would take to install, the NRC is likely basing its planning on unsupportable assumptions.

Appendix 1.1

NRC Staff Comments on EDTF 2.0 Report

Overall Comments

1. Nuclear power plants in the US are extremely robust structures designed with safety margins, as well as defense-in-depth safety capabilities. The facilities are capable of withstanding a broad range of beyond design basis events.
2. The NRC's authority to regulate and to issue orders to its licensees is consistent with its authorizing legislation, including the Atomic Energy Act of 1954, as amended, the Energy Reorganization Act of 1974, and the Energy Policy Act of 2005, as amended. The NRC continues to implement Executive Order (EO) 13865, "Coordinating National Resilience to Electromagnetic Pulses," and will continue to take actions determined to be necessary through the EO's implementation process. Appendix 1 should appropriately recognize the regulatory framework within which the NRC operates and should also recognize that NRC is evaluating whether additional actions regarding EMP are needed for commercial nuclear power plants, consistent with EO 13865.
3. The NRC staff appreciates the opportunity to comment on Appendix 1. However, EDTF allotted limited time to NRC staff to review it and no time to engage with the EDTF on the substance. NRC staff is concerned that the rush to publication of appendix 1 without addressing NRC staff comments may result in inaccuracies. We remain ready to interact further to ensure that the appendix pertaining to commercial nuclear power plants is accurate.
4. Appendix 1 contains several statements without providing a readily apparent basis through citation to authoritative references, and dismisses others, such as the Sandia National Laboratory (SNL) study, without providing a basis for their dismissal (e.g., "The Sandia Study is faulty on more than a dozen assumptions . . .").
5. EO 13865 was not mentioned in appendix 1. The NRC and other federal agencies are currently implementing the EO and will take certain actions as determined through the EO's implementation process.

Comments on the Text of Appendix 1

1. On the first page, in paragraph 2, the EDTF states, "In the NRC's parlance, an EMP is a 'beyond design basis event' (BDBE) that does not have to be taken into account in facility design or be protected against with the use of 'safety-grade' systems, structures, and components (SSC). Thus, no nuclear power plant was specifically designed to survive an EMP event." The Commission addressed this issue beginning in 1967, holding that NRC licensees are not required to protect against enemies of the state conducting an act of war which would include a high-altitude electromagnetic pulse from a nuclear detonation by a nation State. The Commission announced its policy in the final rule, "Exclusion of Attacks and Destructive Acts by Enemies of the U.S. in Issuance of Facility Licenses" (32 FR 13445), which amended 10 CFR Parts 50 and 115:

> The amendments codify the Commission's practice of not requiring applicants for licenses to construct and operate production and utilization facilities to provide for design features or other measures for the specific purpose of protection against (1) the effects of attacks and destructive acts, including sabotage, directed against the facility by an enemy of the United States, or (2) the use or deployment of weapons incident to U.S. defense activities. The protection of the United States against hostile enemy acts is a responsibility of the nation's defense establishment and of the various agencies having internal security functions. The power reactors which the Commission licenses are, of course, equipped with numerous features intended to assure the safety of plant employees and the public. The massive containment and other procedures and systems for rapid shutdown of the facility included in these features could serve a useful purpose in protection against the effects of enemy attacks and destructive acts, although that is not their specific purpose. One factor underlying the Commission's practice in this connection has been a recognition that reactor design features to protect against the full range of the modern arsenal of weapons are simply not practicable and that the defense and internal security capabilities of this country constitute, of necessity, the basic "Safeguards" as respects possible hostile acts by an enemy of the United States.
>
> The circumstances which compel this recognition are not, of course, unique as regards a nuclear facility; they apply also to other structures which play vital roles within our complex industrial economy. The risk of enemy attack or sabotage against such structures, like the risk of all other hostile attacks which might be directed against this country, is a risk that is shared by the nation as a whole.
>
> Furthermore, assessment of whether, at some time during the life of a facility, another nation actually would use force against that particular facility, the nature of such force and whether that enemy nation would be capable of employing the postulated force against our defense and internal security capabilities are matters

> which are speculative in the extreme. Moreover, examination into the above matters, apart from their extremely speculative nature, would involve information singularly sensitive from the standpoint of both our national defense and our diplomatic relations.

Specifically, Section 50.13 of Title 10 of the *Code of Federal Regulations* (CFR), "Attacks and destructive acts by enemies of the United States; and defense activities," states, "An applicant for a license to construct and operate a production or utilization facility, or for an amendment to such license, is not required to provide for design features or other measures for the specific purpose of protection against the effects of (a) attacks and destructive acts, including sabotage, directed against the facility by an enemy of the United States, whether a foreign government or other person, or (b) use or deployment of weapons incident to U.S. defense activities."

Thus, under NRC's regulations, nuclear power plants are not required to defend against enemies of the state. However, 10 CFR 73.1(a)(1) requires that power reactor facilities protect against the radiological sabotage design basis threat (DBT) committed by nonstate actors. Electromagnetic weapons are not included in the description of the DBT in 10 CFR 73.1.

The Commission has continued to consider these issues. In 1984, the Commission denied three petitions for rulemaking seeking to mandate that licensees protect against electromagnetic pulses. The Commission denied the petitions of Ohio Citizens for Responsible Energy, Marvin I. Lewis, and Mapleton Intervenors (19 NRC 1599 (1984)) and stated:

> Based upon results of studies done by the NRC and for the NRC (Sandia National Laboratory Report, NUREG/CR-3069, "Interaction of Electromagnetic Pulse with Commercial Nuclear Power Plant Systems") there is no reason to believe that an EMP would prevent any commercial nuclear power plant from achieving a safe shutdown condition. In addition, the rationale behind the issuance of 10 CFR 50.13, which was upheld in the U.S. Court of Appeals, was that Congress did not intend to implement legislation that would require nuclear power plants to be capable of warding off the effects of hostile enemy acts. This rationale has been reevaluated in the light of the petitions and at this time the Commission finds no information to support a change in policy.

The above regulatory construct notwithstanding, the NRC is addressing the EMP issue consistent with EO 13865. The appendix should recognize the regulatory construct and the fact that the NRC is, nevertheless, addressing EMP consistent with EO 13865.

2. Also on the first page, paragraph 2, the EDTF provides incomplete information on the design and vulnerability of nuclear power plants to

EMP. The US commercial nuclear power plant fleet includes inherent design features (i.e., reactor containment and reactor auxiliary buildings with ceilings and walls that are several feet thick with rebar) that provide protection against the E1 and E2 components of a HEMP. In assessing the vulnerability of nuclear power plants to HEMP, it is important to understand to what extent a HEMP event is capable of degrading nuclear plant systems and the surrounding infrastructure, and whether that damage would exceed the capability of the nuclear power plant (NPP) and its support systems to maintain core cooling.

There are three distinct reactor phases to consider after an EMP event: shutdown, long-term core cooling, and spent fuel pool cooling. All reactors in the US fleet are designed to automatically shut down regardless of the source of the loss of off-site power. Cooling of the spent fuel pool is maintained by the continual addition of water, which is available from a wide variety of sources. The large volume of water present in spent fuel pools renders immediate action regarding the pool following loss of power unnecessary. The NRC is currently evaluating the assets necessary for long-term core cooling as part of the evaluation phase mandated by EO 13865.

The appendix should be revised to address these points.

3. In paragraph 4 of appendix 1, the EDTF describes station blackout. The following information is provided for your consideration in modification of this paragraph. Station blackout (SBO) would occur with failure of redundant EDGs. The NRC adopted regulations that require nuclear plant operators to ensure that a NPP can withstand and recover from a station blackout for a specified duration at 10 CFR 50.63 "Loss of All Alternating Current Power." The duration is plant specific and takes into consideration the reliability and availability of on-site and off-site power sources and vulnerability to weather related events.

NRC Regulatory Guide (RG) 1.155 "Station Blackout," provides guidance for plant operators to meet the requirements of 10 CFR 50.63. The guidance describes the procedures NPP operators may use to cope with SBO and the recommended actions to restore emergency AC power. The SBO procedures are integrated with plant-specific technical guidelines and emergency operating procedures. Nuclear reactor operator training identifies all operator actions that are necessary to cope with a station blackout for the applicable duration. Although SBO events are BDBEs, all NPPs have taken measures to cope with a SBO event of limited duration. Generally, all nuclear power plants assume off-site power will be restored within four hours; this information is detailed in NUMARC 87-00.

The NRC's post-Fukushima Order on Mitigation Strategies expanded US NPPs' ability to safely withstand SBOs of indefinite duration. Enhanced procedures to sustain installed battery and steam-driven core cooling systems, additional on-site generators and pumps to supplement those installed systems, and the ability to bring supplies and equipment from off-site sources mean NPPs are well positioned to maintain public health and safety under SBO conditions.

4. In the sixth paragraph of appendix 1, the EDTF states: "Therefore, the threat posed by EMP to nuclear plants depends on how such an event could challenge the strategies currently in place to deal with electrical system disturbances, from loss of off-site power to indefinite station blackout. Key considerations are whether the safety related EDGs and/or electrical distribution systems would be disabled; whether FLEX equipment would remain functional and FLEX strategies executable; and whether supply of diesel fuel and replacement equipment would be disrupted by a large-scale HEMP event. **The NRC has not done such an analysis** [emphasis added]." The bolded text is not accurate.

The NRC staff performed a preliminary evaluation of impact of a HEMP based on analyses and limited physical testing performed by Sandia National Laboratory (Assessing Vulnerabilities of Present Day Digital Systems to Electromagnetic [EM] Threats at Nuclear Power Plants, December 2009). Taking into consideration the combination of the inherent design features of a typical nuclear plant which can withstand external events (severe weather, earthquakes, lightning strikes) and the standby mode (electrical disconnection) of safety related EDGs, the NRC staff concluded that there is reasonable assurance that core cooling and spent fuel pool cooling will be maintained with permanently installed equipment at US nuclear plants. Consistent with EO 13865, the NRC is currently conducting an analysis which it expects will further validate this position. Additionally, the NRC is currently coordinating with the Department of Homeland Security to evaluate the question of diesel fuel availability.

Appendix 1 should be revised to address these facts.

5. FLEX Equipment: In paragraphs four through eight, the EDTF describes FLEX equipment and BDBE strategy, though it does not accurately capture the nature and scope of these activities. In particular

paragraphs seven and eight, which begin with "One major deficiency" and conclude with "whatever equipment remained functional" are not accurate, almost in their entirety.

NRC Order EA-12-049, "Order Modifying Licenses with Regard to Requirements for Mitigation Strategies for Beyond-Design-Basis External Events" (Reference 3), requires a phased approach for mitigating BDBEs. The initial phase requires using installed equipment and resources to maintain or restore key safety functions, including core cooling, containment, and Spent Fuel Pool (SFP) cooling. The transition phase requires licensees to provide sufficient, portable, <u>on-site</u> equipment and consumables to maintain or restore key safety functions until off-site resources are brought to the facility. The final phase requires maintaining sufficient off-site resources to sustain key safety functions indefinitely. Order EA-12-049 requires NPP operators to develop and implement strategies to maintain or restore core cooling, containment, and SFP cooling capabilities. Full compliance with the order requires procedures, guidance, training, and acquisition, staging, or installing of equipment needed for the strategies following a BDBE.

NEI 12-06 provides specific guidance for the US fleet of operating NPPs on compliance with Order EA-12-049. In order to comply with the post-Fukushima requirements, the NPP operators have purchased and positioned non-safety-related portable emergency equipment such as portable diesel generators to charge station batteries and portable pumps to ensure reactor and spent fuel pool cooling in the event of a long-term SBO. The plants have also made modifications to facilitate connection points for additional equipment (pumps and generators) that may be located external to plant. The NRC inspected and confirmed that all US reactors are in compliance with these post-Fukushima requirements.

While FLEX equipment does not have to meet the 10 CFR Part 50, Appendix B, quality standards, they do meet commercial standards and are required to be maintained in a condition to perform their required actions. As part of its activities addressing the EO, the NRC is determining how best to prevent off-site release of large amounts of radioactivity following an EMP event. The role of FLEX equipment in achieving that objective is being considered.

Appendix 1 should be revised to address these facts.

6. In paragraph six, the EDTF states: "Therefore, the threat posed by EMP to nuclear plants depends . . . The NRC wishes to point out what is being discussed is the *risk* posed by EMP to nuclear power plants, not the *threat*. Please change "threat" to "risk."

   In the same paragraph, the EDTF inaccurately asserts the NRC has not analyzed vulnerabilities of nuclear plants to possible consequences of an EMP event, for example, whether safety-related EDGs would be disabled, whether FLEX equipment would function as expected, and whether the resupply of diesel fuel would be available. The NRC conducted two studies, in 1983 and again in 2009, that analyze the risk of EMP to nuclear power plants. Additionally, consistent with EO 13865, the NRC is currently conducting a follow-on analysis again reviewing this information in-depth.

   The appendix should be revised to address these facts.

7. The NRC staff recommends deletion of paragraph 10, which mentions classified discussions. The sharing of this information should only be to those individuals with the appropriate clearance and the need-to-know basis.

Comments on the EDTF-NRC Discussion Areas

1. Global comments:
   a. The positions under "NRC Position" are not official NRC positions but rather the positions of NRC staff. The NRC Commission has not weighed in on these positions. Please add the word "Staff" so it reads "NRC Staff Position."
   b. EDTF recommendations should not be italicized, because the legend suggests that the NRC agrees with the EDTF recommendation. The NRC has not been provided the opportunity to take positions on these statements.
   c. Please change all stated "NRC Positions" (which, as discussed above, should be referred to as "NRC Staff Positions" to ensure clarity) to the language stated below under Discussion Area Inputs. If the comment to combine issues that are very similar is accepted, please combine responses.
2. Editorial Comments:
   a. In the "Recommended actions" column, many are general statements and opinions rather than actions. Recommend they be revised to include actions or the information deleted.

b. Recommend combining issue areas 1, 2, and 5. The issues are very similar as well as the recommended actions.

c. Recommend combining rows 4, 6, 7, and 8. All are related to emergency diesel generators with similar recommendations.

2. Discussion Area Inputs:

   a. Area 1, NRC Staff Position: Multiple studies have been conducted by the NRC on EMP effects at nuclear power plants. First, in 1983, and that study was updated in 2009 to account for instrument and control digitization. Those studies conducted limited physical testing and then input the results to a complex computer-based modelling system to analyze EMP impacts. The 2009 study validated the 1983 results. In 2010, the 2009 study was supplemented to analyze the effects of geomagnetic disturbances on nuclear power plants. The NRC is further addressing this subject in response to EO 13865.

   b. Area 2, NRC Staff Position: The NRC has conducted low-level testing at two facilities and used that data to better understand EMP impacts with accurate computer-based modelling. The NRC is further addressing this subject in response to EO 13865.

   c. Area 3, NRC Staff Position: The Commission's practice of not requiring applicants for licenses to construct and operate production and utilization facilities to provide for design features or other measures for the specific purpose of protection against (1) the effects of attacks and destructive acts, including sabotage, directed against the facility by an enemy of the United States, or (2) the use or deployment of weapons incident to US defense activities was set forth in 32 Federal Register 13445 and 10 CFR 50.13. The NRC has clearly asserted that it is the responsibility of the United States defense framework to protect against enemies of the State. An EMP attack perpetrated by an enemy of the State would be an act of war. Nuclear power plants are civilian-owned and operated infrastructure and not part of the national defense framework. Consequently, EMP attack was not considered to be a design basis event when nuclear power plants were designed and constructed.

   d. Area 4, NRC Staff Position: According to SNL studies and internal NRC staff reviews, sufficient back-up systems will maintain/allow:

      1. Safe shutdown

      2. Long-term core cooling

3. Spent fuel cooling

A consistent and on-going supply of diesel fuel will be required to maintain the safe shutdown configuration. The NRC is working with the Departments of Homeland Security and Energy, and the National Security Council to address the logistics associated with these deliveries.

The NRC staff is further addressing this subject in response to EO 13865.

e. Area 5, NRC Staff Position: NRC staff does not anticipate significant penetration of EMP fields into a reactor containment and auxiliary buildings due to design of the structures. Both types of structures are category 1 seismic buildings with significant amounts of concrete and rebar. The NRC is further addressing this subject in response to EO 13865.

f. Area 6, NRC Staff Position: EDGs are normally de-energized, disconnected from safety-related systems, and typically located in a seismic category 1 building made of cement with rebar. Based on the Sandia studies as well as National Institute of Standards and Technology's concrete signal attenuation standards, significant signal attenuation exists with these types of structures. The robust design should protect the EDGs from induced EMP illumination and transmission currents. The NRC is further addressing this subject in response to EO 13865.

g. Area 7, NRC Staff Position: The NRC staff generally agrees that greater assurance is needed for an on-going diesel fuel supply to the nuclear power plants. The NRC staff has been working with the Departments of Homeland Security, Energy, and the National Security Council to establish the logistics necessary to ensure timely diesel delivery.

h. Recommend deleting area 8 entirely because it is addressed by prior items.

i. Area 9, NRC Staff Position: Spent fuel pools will remain safe as long as sufficient water is replenished. Because the pools are unpressurized and contain large volumes of water, replenishing the water is neither difficult nor of great urgency following an EMP event. Furthermore, consistent with previously-established Commission positions, wet- and dry- spent fuel storage are considered safe.

j Area 10, remove "The NRC agrees." NRC Staff Position: NRC licensee site security is required to prevent radiological sabotage regardless of the conditions. According to 10 CFR 73.55(o), Compensatory Measures, when a degradation occurs, nuclear power plants are required to implement compensatory measures to ensure they maintain the ability to detect, assess, interdict, and neutralize the design basis threat. A site's ability to carry out these procedures for weeks to years has not been analyzed. The NRC is further addressing this subject in response to EO 13865

k Area 11, NRC Staff Position: The NRC staff agrees to the extent that NRC licensees are not required to harden to DOD or military standards. However, some nuclear power station features may meet military standards by virtue of how they were designed for other purposes.

l. Area 12, NRC Staff Position: The 2009 SNL study specifically analyzed the "smaller" EMP weapons and indicated that such impacts would likely be low. The NRC staff is further addressing this subject in response to EO 13865.

m. Area 13, NRC Staff Position: While EMP is a BDBE, the NRC staff has high confidence that nuclear power plants will shut down safely as designed. Regardless of the reason for the loss of power, all shutdown instrumentation and controls are fail-safe and automatic.

Also, in Recommended actions, the EDTF states, "During the accident at Three Mile Island, an incorrect reading of a valve position on a digital readout caused an inadvertent release of radiation." TMI 2's core melt situation is completely unrelated to EMP; the discussion should be deleted

n. Area 14, NRC Staff Position: Some nuclear power plants have upgraded their safety systems with digital technology, and others have an interest in performing these upgrades in the near future. In approving the use of digital safety systems, the NRC staff considers diversity of actuation means, defense-in-depth, and possible failure modes. Note that on loss of power, safety systems are designed to fail in a safe mode. The NRC is further addressing this subject in response to EO 13865.

o. Area 15, NRC Staff Position: FLEX assets are maintained on-site at all reactors and in two additional sites in separate storage facilities: one in Memphis and the other in Phoenix. All FLEX equipment is stored de-energized and disconnected from the grid. The NRC, in addressing EO 13865, is considering the role of FLEX equipment in preventing significant release of radioactivity off-site following an EMP event.

p. Area 16, NRC Staff Position: If all engineered and proceduralized mitigation measures failed and a meltdown were to occur, there is a very large uncertainty in off-site consequences due to the large uncertainty in size of releases and variability in meteorological conditions (wind speed, direction, precipitation, etc.). Early fatalities from high acute exposures are not expected. Early severe health effects require both high doses and high dose rates; these conditions, if they were to exist, are expected to be limited to areas near the site. With prompt protective actions, off-site doses can be kept to low levels. The NRC staff has not analyzed scenarios with extended and widespread failure of off-site protective actions, which continue for more than several days. Without prompt protective actions, off-site doses may reach levels where there is an elevated lifetime risk of cancer to off-site populations. For the population, failure of access to food and clean drinking water would likely prove much more hazardous to health and safety. The NRC is further addressing emergency planning impacts from EMP in response to EO 13865.

q. Area 17, NRC Staff Position: Off-site power restoration is outside the NRC's statutory authority. In performing the analyses required by EO 13865, the NRC will follow the off-site power assumptions provided by the Department of Homeland Security.

Appendix 2

Enterprise Capability Collaboration Team (ECCT)

Background on EMS Superiority in the Spectrum

Imagine driving on a two-lane road through a small town with very little traffic. That was the extent of the electromagnetic spectrum (EMS) according to a Federal Communications Commission (FCC) chart produced around 1970. However, today's EMS can be likened to trying to fit Atlanta or Washington, DC, traffic during rush hour through that same small town. Use of the EMS has expanded exponentially, and the current FCC radio frequency allocation table[1] now includes telecommunications (4G), weather radar, datalinks, satellite communications, radio navigation, and much more.

Modern warfare is highly dependent on the EMS, and maintaining an advantage within this domain is necessary to enable Joint Force commanders to gain tactical, operational, and strategic advantage. Joint doctrine defines electromagnetic spectrum operations (EMSO) as coordinated military actions to exploit, attack, protect, and manage the electromagnetic environment to achieve the commander's objectives. EMSO refers to all actions taken in the EMS or involving the EMS regardless of their nature or adversary involvement to compete and win against peer and near-peer adversaries in modern conflict.

Current joint and service doctrine emphasizes a view of the EMS as a resource to support operations in the other operational domains, at the expense of the view that the EMS is a distinct domain in which conflicts can be won or lost. US and allied platforms, weapon systems, and kill chains rely on the EMS—a reliance increasingly challenged by competitors and adversaries, especially impacting the air and space domains.

The EMS is defined by rapid technological change, contested and congested battlespace, and intense competition for control and superiority. In an era refocused on great power competition and readiness for the peer fight, controlling the EMS is irrefutably linked to our combat lethality and societal resilience.

Peer and near-peer competitors have organized, trained, and equipped with advanced EMS capabilities, integrating cyberspace, space, and air assets into comprehensive, integrated air defense systems; these combined manned and unmanned aircraft, sophisticated air and missile defenses, ballistic missiles, cruise missiles, hypersonic vehicles, as well as ground-, maritime-, air-,

1. "Radio Spectrum Allocation," Federal Communications Commission, 7 May 2019, https://www.fcc.gov/engineering-technology/policy-and-rules-division/general/radio-spectrum-allocation, https://transition.fcc.gov/oet/spectrum/table/fcctable.pdf.

space-, and cyberspace-based electronic warfare (EW) capabilities, present growing challenges to the Joint Force's ability to achieve control of the air, space, cyberspace, land, and maritime domains.

Competing powers have witnessed America's dominance on the battlefield and perceive our reliance on the spectrum as a major vulnerability. In some instances, the US has not kept pace, and our technological advantages are eroding. Some of the contributing factors include (1) lack of a comprehensive and coherent EMS strategy and doctrine; (2) EMSO not perceived as a US military core competency; and (3) deteriorating knowledge, expertise, and acumen of the EMS in almost all Americans.

EMS experts have agreed that the preponderance of EMS knowledge resides within the US's older generation, working on specific projects and having limited awareness of other EMS capabilities ongoing with other military or civilian institutions. The lack of EMS training provided over time has produced Americans with limited knowledge in the EMS. Over the last three decades, this has diminished EMS advocacy, strategy, and vision within US leadership circles.

The intent of this paper is to adjust America's Joint Force and civilian (including industry, academia, defense contractors, etc.) policy perspectives on the importance of gaining and maintaining dominance in the EMS, enabling superiority in the air, space, cyberspace, land, and maritime domains.

ECCT Recommendations

The Chief of Staff of the Air Force (CSAF) is addressing this lack of EMS management, from a service specific point of view, by directing the ECCT to deliver executable courses of action to gain and maintain EMS superiority across the range of military operations in an increasingly congested and contested EMS. Brig Gen David Gaedecke, director of EMS Superiority, presented the ECCT outbrief during the January 2019 Weapons and Tactics Conference. CSAF approved three recommendations: (1) establish an EMS Superiority Directorate within Headquarters Air Force, (2) restructure the EW reprogramming enterprise, and (3) reinstill a culture of EMS awareness across the Air Force.

Presently, the Headquarters Air Force (HAF) staff is standing up the directorate and corporate panel. This plan, once implemented, will drive development of policy and changes to current guidance on EW and EMSO and management. HAF and the Air Force major command (MAJCOM) staffs will provide new policy and revised guidance to squadrons employing EMS-dependent platforms or systems. It may drive changes to tactics, techniques, and procedures and present improved doctrine, training, and education related to attaining and sustaining EMS superiority.

Improving the US doctrine, education, training, and exercising/war gaming with regard to the EMS will (1) identify and define characteristics and requirements for the EMS warriors; (2) assess and formalize training and education of EMS capabilities for all US personnel throughout their careers; (3) review and determine changes in doctrine and strategy to integrate EMS responsibilities, operational objectives, acquisitions, and concept of operations across the US military, industry, and private sectors; and (4) review and incorporate EMS objectives into US exercises and war gaming to prepare military and civilian procedures in the advent of catastrophic EMS degradation due to an electromagnetic pulse, intentional/inadvertent EMS disruption, or natural negative effects due to a geomagnetic disturbance (GMD).

During the conference, the commanders of Air Combat Command (ACC) and Air Education and Training Command (AETC) agreed to restructure the reprogramming enterprise and reinstill a culture of EMS/EW awareness. CSAF approved a holistic review of education, training and exercises/war gaming. Correspondingly, AETC will take action to combine separate EMS, EW, signals intelligence (SIGINT), and Weapons School academics into standardized EMS force development academics (basic [EMS100] through advanced [EMS400]) for all Airmen. AETC will consolidate all inputs and develop EMS courseware to be instructed/planned across the Air Force at all levels of commissioning/enlistment, initial qualification, upgrade training, professional military education, and live-fly/virtual exercises and war gaming.

Executing similar recommendations across the US in a whole-of-government approach will enable the US military and civic leaders, military and civilian populace, industry, academia, and infrastructure personnel to be better educated on the challenges of understanding and dominating the EMS, provide a more robust and resilient populace and infrastructure, and ensure our ideals of individual freedom and our way of life.

Actions Completed

In December 2018 the LeMay Center hosted an EW/EMS Doctrine Rewrite Summit to update EW/EMS doctrine. There were approximately 20 experienced personnel from RC-135 and EC-130 aircraft, 53rd Wing, Air Force Special Operations Command, Air Force Space Command (AFSPC), Air Force Global Strike Command (AFGSC), ACC, Air Force Mobility Command, and Cyber Command to rewrite the Air Force (AF) Annex 3-51 Electronic Warfare Doctrine. After reviewing the current doctrine and the draft JP 3-16 Joint Electromagnetic Spectrum Operations (JEMSO) documents, the group composed a draft Annex 3-51 Electronic Warfare and Electromagnetic Spectrum Doctrine which defined EW in air, space, and cyber and incorporated JEMSO concepts into Air Force structure. The Annex 3-51 EW/EMS Doctrine is in final coordination, with estimated completion date of 31 July 2019.

The LeMay Center drafted a review process for AETC coordination, at the direction of CSAF, to review all EW, SIGINT, Weapons School, and EMS academics. Correspondence between AETC and MAJCOMs will allow for the creation of standardized EMS force development academics for all Airmen. The academics/courseware will provide EMS education for every Airman at a basic level to a more specific advanced EMS course for war gamers and joint planners.

The Way Forward

The Deputy Chief of Staff, Strategy, Integration and Requirements (AF/A5) will establish an EMS Superiority Directorate. A General Officer will lead this new directorate that will be responsible for enterprise-wide actions and unity of effort to deliver EMS superiority in all domains.

The Director, EMS Superiority will assess the value of creating an EMS Enterprise Integration Group linking MAJCOM staffs and Air Force Warfighting Integration Capability counterparts. This group will be responsible for developing enterprise-wide EMS strategy and corresponding investment and divestment priorities. The director will chair the group and establish linkages with AF/A8P and A8X for program objective memorandum planning and programming actions.

AF/A5 will stand up a functional integration team in AF/A5A, led by a colonel who synchronizes with the EMS Superiority Directorate. AF/A5 will embed EMS experts in all A5A functional areas (e.g., Capability Development, Futures/Concepts, etc.), and establish an EMS Superiority Panel.

The Deputy Chief of Staff of Plans and Programs (AF/A8) will establish an EMS Superiority Panel that will manage all AF EMS/EW equities. A colonel will lead the panel and will report to the EMS Superiority Director and identify an office of primary responsibility and a point of contact for EMSO.

All MAJCOMs should designate a dedicated EMSO staff element (recommend Division) with effective linkage to the EMS Superiority Directorate.

Consolidate and Modernize EW Reprogramming Enterprise

ACC will migrate the existing Specialized Electronic Combat and Reprogramming Environment (SPECTRE) infrastructure into an Air Force common integrated programming platform for EW. Acting as an application store, the enhanced SPECTRE will securely develop, test, host, and deliver the EW missionware using modern, industry standard developer tool chains. SPECTRE will integrate EMS effects while identifying and mitigating EMS fratricide by employing appropriate model-based systems engineering and advanced modeling and simulation.

Offices under the Secretary of the Air Force will develop an appropriate continuous authority to operate that will facilitate the rapid fielding of secure missionware and consolidate reprogramming centers. To accomplish this, ACC will consolidate the Air Force's two Operational Reprogramming Centers into a single organization that will program and reprogram EMS/EW systems as well as sensor engineer Combat and Mobility Air Forces systems and platforms. Individual MAJCOMs will continue to set the programming and updating priorities within their portfolios. ACC will also work with AFSPC to identify mechanisms to ensure unity of effort while deconflicting EW effects. Applicable Air Force Life Cycle Management Center organization(s) will partner with the Operational Reprogramming Center to develop a system-specific missionware capability that supports portability of threat-specific techniques, threat simulations, and other system attributes. SAF/CN will identify and accredit a suitable Secure Development Ops Environment for this interchange.

EMS Culture and Awareness

To ensure EMS culture and awareness across the range of military operations, this paper recommends a three-phase approach: Near Term, Mid-Term, and Long-Term. The knowledge of an EMS war fighter is not limited only to EW but constitutes the entire domain. To make certain a cohesive understanding and integration of the entire EMS among Air Force civilians, active duty, and leadership for future EMS superiority, the following minimum recommendations are provided for implementation across the US:

Near Term:

1. Author US EMS policy and doctrine
2. Facilitate AF service support to joint doctrine's plan for Joint EMS Operations (JEMSO) and provide the AF's position on service execution for the commander of Air Force Forces (COMAFFOR)'s staff to execute

EMSO operations in support of the Joint Force Commander's Theater Campaign Plan

3. Review and consolidate US EW/EMS academics and courses

Mid-Term:

Consolidate EMS academics and create standardized, multi-layered academics to instill a culture of EMS awareness in the US. Instill EMS objectives into all major exercises, large force employment, and war gaming.

EMS 100: Basic EW and EMS education to be taught at basic training, service academies, Reserve Officer Training Corps, officer training school, and so forth.

EMS 200: Intermediate EW and EMS academics and tabletop exercises to be reinforced at all military initial qualification training and technical schools; special emphasis to identify and instruct future EMS subject matter experts. This course will also be used as a refresher course for general officers.

EMS 300: Advanced EMS education for military planners, industry leaders, academia, and EMS leaders of tomorrow. The course would include academics, strategic/operational doctrine, and tabletop exercises and requirements for participation in exercises where attendees ensure they execute EMS objectives in a contested environment against a peer adversary or due to a GMD.

EMS 400: Additional advanced EMS academics for military and civilian planners and military EMSO staffs. Requirements include advanced academics/doctrine and tabletop exercises, with a graduation exercise—participation in an exercise where attendees ensure they execute EMS objectives in a contested environment against a peer adversary or due to a GMD.

Long-Term:

Focus on three critical lines of effort collectively required for protecting this core competency:

1. Expertise and Operating Concepts;
2. Bridge to Advanced Technology and Competitive Capability;
3. Institutionalize EMS Resurgence and Leadership.

To develop EMS doctrine and training, AETC will explore, develop, and produce new and innovative concepts and doctrine that expand on historic EW principles in favor of enterprise EMSO. Outdated doctrine and instructions will be rewritten emphasizing the EMS as a war-fighting maneuver space addressing joint and multi-domain EMSO. Correspondingly, AETC will act to combine components of separate EW, SIGINT, Weapons School, and EMS academics into standardized EMS force development academics (basic through advanced) for all Airmen—military and civilian.

AETC will assess the creation of an EMS Center of Excellence made up of Airborne EW, Space EW, Cyber EW, and Joint expertise responsible for EMS education, leadership training, exercises, war games, and sophisticated technical acumen.

The EMS Superiority Directorate, in coordination with Air Force Manpower and Personnel (AF/A1), will provide oversight for talent management of EMS experts to ensure development of future joint EMS leaders. This will enable the US to develop and manage EMS talent.

MAJCOMs and the LeMay Center will emphasize exercising and training in a realistic EMS-contested environment in order to develop tactics, techniques, and procedures and build situational recognition and proficiency in a degraded EMS environment.

Summary

Lacking recognition of the EMS as a war-fighting domain, there is no true forcing function to drive the US to do the hard thinking, experimentation, and war gaming required to develop and validate the theory and doctrine we lack. The tasks included in this Implementation Plan are designed to begin the process of restoring the Air Force's ability to gain and maintain EMS superiority. As champion, the Director, EMS Superiority, will stand up and lead the directorate and provide oversight of the creation of an EMS Superiority Panel, the modernization of EW reprogramming, and instantiation of a culture of EMS/EW awareness across the Air Force. The support of Airmen across the Air Force is necessary to assure effective implementation.

Appendix 3

A "Typical State's" Perspective on EMP and EMS Threats to the Electric Grid

Overview

As in many other states, policy makers in Alabama have heard constituents are interested in learning what utilities and state government are doing to protect the state and nation's security and prosperity, including threats to the electric grid. Policy makers and their constituents have engaged utilities in Alabama to discuss and discover the magnitude of the threats faced by the grid and the strides taken by utilities to protect and secure infrastructure against natural and man-made hazards.

Alabama is a diverse state in terms of electrification. A variety of electric providers, including Alabama Power, the Tennessee Valley Authority (TVA), and the state's many nonprofit rural electric cooperative and municipal electric utilities, operate together to provide power to the state. The strong relationships among these partners are characterized by cooperation, a passion for community engagement, and sustained forward progress in growth and industrial development that has measurably increased the quality of life for all Alabamians. Additionally, Alabama's electric sector stakeholders enjoy productive and cooperative relationships with the state's policy makers and regulators. In the face of hazards including hurricanes, tornadoes, ice storms, heat waves, and severe windstorms, these partners cooperate to ensure the reliability and prompt restoration of service to customers.

Alabama is also a diverse state in terms of its infrastructure and economy. While not as populous as some states, it is home to a deep-water port, a robust automotive manufacturing industry, and several military installations. The state also has a robust agriculture industry and a long history with aerospace manufacturing and technology. Additionally, Alabama continues to capitalize on its strong partnership with the Department of Defense (DOD) to develop and host next-generation war-fighting technologies, such as the Air National Guard's 187th Fighter Wing's F-35 Lightning II aircraft.

The Alabama Emergency Management Agency (AEMA)—due to its unique position as the nexus of infrastructure protection and restoration from all hazards, its mission to coordinate with partners on enhancing the state's capacity for community resilience, and its interfaces with military partners—was tasked to convene a series of discussions among industry leaders and key stakeholders on the topic of grid resilience. These discussions identified opportunities and barriers for how a "typical state" would protect its infrastructure and citizens.

As a capstone to this effort, AEMA worked with Air University and the Curtis E. LeMay Center for Doctrine Development and Education to invite representatives from Alabama's energy sector and other interested stakeholders to participate in the Electromagnetic Defense Task Force (EDTF) 2.0 summit held at Maxwell Air Force Base in May 2019. Attendees included representation from Alabama Power, the TVA, the Alabama Rural Electric Association of Cooperatives, PowerSouth Energy Cooperative, and the Alabama Municipal Electric Authority, as well as representation from the Montgomery Area Chamber of Commerce, the Air Force, the Alabama Air National Guard, the Department of Homeland Security, and the office of Alabama Governor Kay Ivey.

After participating in EDTF discussions and hearing perspectives from other states, utilities, and federal partners, Alabama's attendees met to develop a list of open questions and consensus points about how a typical state might move forward with mitigation. The items listed below summarize what work remains to be done in closing the information and mitigation gaps for electromagnetic pulse (EMP) and electromagnetic spectrum (EMS) threats to the grid. This is not an Alabama-specific plan for addressing the issues; rather, it is intended as a guide for policy makers and presents the current condition of the state regarding EMP and EMS electrical grid protection. While the participants expressed confidence that counterparts in other states would hold a variety of views on these topics, the participants also felt the major issues and questions raised would likely be representative of a typical state.

The thoughts and perspectives provided by the Alabama focus group have been distilled into a list of nine open questions that must be answered to enable the nation to tackle EMP and EMS hardening of the electric grid. Additionally, three overarching strategic obstacles were identified; these will need deliberate and collaborative public-private solutions for the nation to progress toward resilience against these threats.

Disclaimer: The reader should note that the issues outlined below present only a general synthesis of themes and questions discussed during the EDTF. The material presented should not be construed as representing the opinion or position of any individual who participated in the summit, any employer or institution represented, or the state of Alabama.

Discussion: Open Questions, Moving Forward

1. **The nation needs to decide if it will implement EMP/EMS mitigation measures in either a holistic or a piecemeal fashion**.

There are two primary concepts of applying EMP/EMS mitigation measures across the grid.

a. An approach that focuses only on identified critical paths and nodes in the generation, transmission, distribution, and load chains. Such an approach might provide a means of mitigation for known critical infrastructure and loads that are essential to national defense and homeland security. This might be dubbed a critical path approach.

b. Applying "defense in depth." Such an approach would see EMP/EMS mitigation measures applied across the entire grid ecosystem. It would also include efforts to enhance the redundancy and survivability of the grid against a variety of other known threats, including natural hazards such as geomagnetic disturbance (GMD).

It is possible that some combination of both approaches might be realized. By focusing first on critical paths, some level of survivability could be attained today, while further resilience for the system could be achieved tomorrow as mitigation measures are applied across the grid.

2. Resilience against EMP/EMS threats must be incentivized.

Utilities in any state will need to be incentivized before undertaking significant mitigation projects. In general, questions arose around two facets of incentivization: the incentives themselves and the lens through which the stakeholders will understand the incentives.

What are the factors that will ultimately drive the utility industry on the one hand, and the DOD on the other, to commit to implementing grid resilience measures as a collective undertaking?

What framework will be used to analyze incentives? Attendees expressed confidence that industry analysis will be financially driven while the DOD is likely to take a threat-based approach to analysis.

Incentivization of EMP/EMS mitigation measures is a wicked problem due to the complex factors involved. Primarily, the attendees felt that the principal factors were (a) funding, (b) the evident unknowability (at least at the time of this report) of what constitutes a proper and prudent mitigation strategy, and (c) disagreements among the data regarding the magnitude of EMP/EMS threats to the grid and its infrastructure.

3. Better data and information sharing is essential.

While it is in principle a basic concept, participants felt achieving an enhanced commitment to information and data sharing across industry, government (both regulators and policy makers), defense, and homeland security stakeholders should be prioritized.

4. Business cases for EMP and EMS mitigation must be developed.

More work is needed to build the business case for investing in mitigation measures. This is an area where a contrast between defense and industry officials becomes evident.

From a defense perspective that views the employment of EMP and EMS techniques as weapons of war, the nation's survival cannot be measured with cost-benefit analysis; that is, in the face of existential threats, ensuring survival is—on its own merits—a complete business case.

On the other hand, industry requires mitigation measures being bought at a defined cost—regardless of whether that cost is currently known or agreed to. Thus, mitigation is by necessity a matter of managing limited resources, both financial and material.

The attendees agreed that hyperbolic language about EMP and EMS threats was generally unhelpful in moving discussions forward on these issues. A useful approach is anchoring discussion on the topics of technical vulnerabilities and mitigation challenges, leaving aside speculation about the socioeconomic impacts of a cascading infrastructure failure.

5. The mindset regarding EMP and EMS threats must change across industry, government, and other interested stakeholders.

It is important to note the dark tone of some conversations around EMP and EMS threats belies the underlying mindset about tackling the problem; that is to say, the discourse around these issues has become securitized. To make progress, conversations around EMP and EMS threats must be desecuritized and reconceptualized. They must be viewed as challenges to the resilience of our nation's infrastructure and as opportunities for industry and public-private partnerships to drive increased economic and national security in the future.

6. Effective coordination structures are needed to implement EMP and EMS mitigation measures.

At the state level, formalized coordination structures will be needed to bring together industry, utilities, government, subject matter experts from defense and homeland security, and the research community, to collectively address the challenge of EMP and EMS mitigation. It is essential that states and their utilities be empowered to control their own affairs to the max extent possible while also being provided with an opportunity to function as one cohesive team in the undertaking.

Likewise, states will need to develop shared, cooperative strategies that integrate vision, goals, and objectives across all stakeholders. Such strategies must be sufficiently broad to allow for future refinement in data and mitigation measures, while also synchronizing stakeholders around resilience activities.

7. A comprehensive vantage point must be maintained that considers EMP and EMS threats in the balance of all hazards and threats.

A fundamental principle of emergency management in the United States is the "all hazards" approach. In this framework, government and the private sector coordinate to address both natural and man-made hazards through a comprehensive system that applies mitigation, preparedness, response, and recovery plans and resources in a consistent manner regardless of any threat. This all hazards approach must be maintained when dealing with EMP and EMS threats. Any resilience and mitigation measures must be implemented with an eye toward other threats, especially natural hazards such as hurricanes, tornadoes, windstorms, ice storms, and GMD. Furthermore, mitigation efforts must also consider unconventional threats such as cyberattacks and terrorism.

8. An effective risk communications strategy must be developed.

Decision makers in both the public and private sectors frequently make decisions in the context of risk. As such, efforts to mitigate against EMP and EMS threats must be communicated to stakeholders using the language of risk. Simplified, this means talking about the risks of investing in mitigation (sunk costs, lost productivity in other areas of effort) and the risks of not investing in mitigation (failure of the grid, degraded national security). Ultimately, there is risk in every scenario and outcome; as such, it is imperative that the issues of EMP and EMS mitigation not be reduced to a binary question of identifying a single, low-risk course of action among a pool of evident alternatives. A combination of many different measures must be weighed in the context of the complex environment in which those measures will be implemented.

9. **Mitigation efforts must focus not only on infrastructure hardening but also on policies, plans, and procedures.**

The electric utility industry has made significant progress over the past several decades by optimizing plans, procedures, and operational protocols with an eye toward increased safety and enhanced efficiency. In the energy industry, resilience is—in large part—due to intensive training of highly skilled professional system operators and relying on good policies and procedures that are continually improved. There is a culture of high reliability in the industry. Lessons learned through achieving that culture should be considered when contemplating the path forward for addressing EMP and EMS threats.

Perceived Barriers to Progress

In addition to the areas of opportunity identified during the Alabama discussions, participants spoke broadly to three overarching strategic obstacles that must be overcome if the nation is to effectively mitigate EMP and EMS threats to the electric grid. These obstacles were perceived by the participants as threats to the resiliency and national security of the United States.

Strategic Obstacle no. 1: Aligning public policy interests at the state and federal levels.

At the state level, the most evident strategic obstacle is education. This includes education of both the public and policy makers.

K–12 education: Electric utilities, like all industries, rely on a trained, qualified, and engaged workforce. The delivery of high-quality science, technology, engineering, and mathematics (STEM) education is a strategic priority for the energy industry. Without successful STEM programs, the industry will suffer, as will the nation's resilience. **State-level policy makers must understand STEM education as an essential pillar in our nation's national security.**

Policy-maker education: Awareness of the complexity and vulnerabilities of our nation's infrastructure is limited among state-level policy makers. This is a problem across all infrastructure sectors and is especially true regarding the electric grid, EMP and EMS threats, and the nexus of electric power with all other aspects of life in a modern society. **A deliberate program should be undertaken to educate state-level appointed and elected leaders about enhancing the resilience of the nation's electric grid.**

At the federal level, three closely related concerns constitute a strategic obstacle: politics, funding, and regulation.

Politics: The politics of the energy industry on the national stage are complex. With regard to mitigating against EMP and EMS threats, many opinions exist as to the magnitude of the threat, the most appropriate means to mitigate against the threat, and who should be leading the decision-making process for mitigation efforts. At a basic level, the public-private policy apparatus that drives the energy industry is optimized to address the day-to-day delivery of clean, efficient power to the American public. **Tackling a complex problem such as EMP and EMS threats is well outside the norm of issues for many of those involved in energy policy discussions and will require a realignment of policy interests within the broader context of our nation's ongoing energy debates.**

Funding: Obtaining funding for EMP and EMS mitigation efforts is a necessity, and the federal government must facilitate a solution to this need. Currently, EMP and EMS threats are collectively viewed as either "a national security/defense issue" or as an "inherent vulnerability of the electric grid." Those who view the issue as one of national defense tend to point toward Congress and defense appropriations as the best funding source for mitigation efforts and leadership in defining the nature and extent of threats. On the other hand, those who view the issue as one of the inherent complexities of the nation's infrastructure tend to look toward industry to find its own solutions within the confines of existing rate structures, regulation, and business income. **The nation must decide whether the EMP and EMS threat is a national defense issue. Further, the nation must collectively determine how best to drive mitigation efforts: through federal appropriations and incentives, through regulation and existing utility funding streams, or through some combination of those avenues.**

Regulation: Lastly, at the federal level, regulators with influence in the energy production and transmission domains should work to gain awareness of how EMP and EMS threats are impacting electric utilities across the nation and work to provide effective regulatory guidance and support for future mitigation activities. **Importantly, the attendees stressed that no material progress on mitigating against EMP and EMS threats would be possible without strong and clear support from federal regulators.**

Strategic Obstacle no. 2: Articulating clear and measurable near- and long-term action items.

Stakeholders in the energy sector need actionable plans for mitigating against EMP and EMS threats. Action plans are needed for mitigation measures and implementation processes and to further define requirements and standards.

Planning element 1: Mitigation courses of action. States and utilities need courses of action and alternatives for mitigation measures that include cost/ benefit estimation tools.

Planning element 2: Implementation processes. States and utilities need roadmaps and templated processes for mitigation measures. These should include alternatives such as incremental mitigation measures—such as leveraging the attrition of old and obsolete components as an opportunity to introduce EMP- and EMS-hardened systems.

Planning element 3: Requirements and standards. There is currently no clear consensus across interests in the defense and energy domains to the extent of appropriate mitigation measures. Once such a consensus is achieved, a requirements- and standards-setting framework will be needed to guide necessary changes in rules, regulations, laws, and baseline minimum mitigation levels. Such a framework must provide a mechanism for coordinating efforts across both technical and policy domains.

Strategic Obstacle no. 3: Overcoming the state/regional dichotomy.

Currently, energy production and transmission in the United States are operationally regulated and managed at two primary levels: states and regions. Depending on the system in question and the level of analysis, there is overlap between these two domains. To proceed with EMP and EMS mitigation measures, congruence between the domains must be achieved. Fundamentally, the nation must decide whether EMP and EMS mitigation is to be pursued within the geographic boundaries of any particular state or at the regional—or national—level. Resolving this question and determining the best level at which to focus mitigation efforts is a challenge of feasibility—technically, financially, and politically.

Appendix 4

Recommendations Checklist

- ☐ Establish information sharing within the government, industry, and academia
  - ☐ Create a national repository to track infrastructure resiliency initiatives to help minimize duplication of efforts and enhance benchmarking of successful projects
- ☐ Garner public support through public outreach and media campaigns
- ☐ Develop a nationwide plan with Department of Homeland Security (DHS), US Northern Command (USNORTHCOM), and US Strategic Command, and include local communities
- ☐ Ensure electric power grid and supervisory control and data acquisition is not dependent on 5G
- ☐ Build a community of experts
  - ☐ Invest in science, technology, engineering, and mathematics (STEM)
  - ☐ Incentivize STEM graduates and engineering disciplines to research the mechanics of EMS hardening
- ☐ Develop a cohesive strategic plan involving national and local governments
  - ☐ Involve the Federal Emergency Management Agency and establish geomagnetic disturbance (GMD) / electromagnetic pulse (EMP) as a natural disaster
  - ☐ Ensure 5G's recovery steps are included as 5G becomes more prevalent
  - ☐ Harden and utilize cells-on-wheels
  - ☐ Partner with American Radio and Relay League and Military Auxiliary Radio System to integrate ham radio into the national emergency and redundant communications strategy
- ☐ Incentivize industry to implement shielding standards and protect equipment
  - ☐ Research implementation of EMP-Star rating
  - ☐ Set standards for tiered rating
  - ☐ Award cities for EMP resiliency

- ☐ Increase the pace and reduce the cost of 5G development by allocating mid-band spectrum (sub 6Ghz) for mobile assets
  - ☐ Ensure supply chain integrity of 5G equipment for security
  - ☐ Educate students and military on vulnerabilities of 5G and potential threats
  - ☐ Ensure 5G networks are resilient, redundant, and resistant to GMD/EMP
- ☐ Recognize the electromagnetic spectrum (EMS) as a domain and incorporate EMS into doctrine
  - ☐ Create a culture of EMS awareness
  - ☐ Translate/publish/understand adversary doctrine
  - ☐ Develop golden hour response plan for EMP recovery
- ☐ Educate military members on EMS utilization and vulnerabilities beginning with initial military training and continuing through career
  - ☐ Incorporate EMS training into LeMay Wing and Group Commander's course
- ☐ Train and exercise in an EMS-degraded environment
  - ☐ Incorporate GMD/EMP into community and base exercises
  - ☐ Stand up EMS attack "Red Team"
- ☐ Develop cognitive electronic warfare and artificial intelligence to deliver mass alert from GMD/EMP
  - ☐ Develop software-defined/reconfigurable radios and laser-based communications
  - ☐ Research UAV or balloon-based repeaters for radio communication
- ☐ Invest in pre-positioned shielded assets, including generators, fuel, and communications equipment, which are placed throughout the nation and in allied countries
- ☐ Streamline the acquisition process for EMP shielded equipment to allow quicker development and unit testing
- ☐ Develop tax incentives for implementing EMP hardening standards
- ☐ Develop micro-grids that are hardened for EMP and cyber for critical facilities and then branch out to all military bases
- ☐ Evaluate ways to detect and prevent threats across 5G networks

- ☐ Institutionalize EMS awareness in leadership positions
- ☐ Partner with universities to develop "whole of society" EMS education programs and strategies
- ☐ Strategically message that the US is prepared for EMP attack and will regard it as a crime against humanity
- ☐ Develop leadership roles for specific situations, for example DHS will lead recovery after GMD, while USNORTHCOM will lead recovery and retaliation after EMP
- ☐ Manage the workforce to find and retain experts in EMS operations and maintain corporate knowledge
- ☐ Ensure EMP shielding is implemented in new military construction as the cost is much lower

Appendix 5

EDTF 2.0 Executive Outbrief Slides

Track I: EMSO

What sustainable, efficient, and cost-effective approaches do we need to invest in/develop right now to keep Joint Force capability operational (viable) in a severe EMS-degraded environment?

1. Doctrine: common understanding/lexicon, war fighting
2. Organization: integrated across staff/echelon, institutionalized in military and civic arenas
3. Training/Education (individual/collective): whole force, readiness, demand signal, objectives, OPFOR, venues, M&S, T&E (OT/DT)
4. Material: cognitive/AI, meshed networks, distributed, autonomy, man-machine, software-defined/reconfigurable, multi-mission, MDC2/EMBM (J2/3/6 operationalized)
5. Leadership: advocacy/influence, resourcing, governance, focus, “seat at the table”
6. Personnel: available expertise, workforce management (traceable, career)
7. Facilities: ranges, LVC, COE (virtual distributed? DEVOPs: tech/ops?)

Deterrence

What sustainable, efficient, and cost-effective approaches do we need to invest in/develop right now to keep Joint Force capability operational (viable) in a severe EMS-degraded environment?

1. Whole of Government Strategic Messaging
   a. Attack with HEMP is act of war and crime against humanity
   b. Expect severe repercussions from US, allies, and coalition
2. Educate, train, exercise, war game to real-world scenario and make resources available
   a. Military capabilities emphasis
   b. Civic/DOD interoperability, cooperation, and training
   c. Degraded EMS focused exercises—realistic replication

   d. EMP/EMS Red Team creation
3. NORTHCOM/STRATCOM/DHS integration and sharing resources, knowledge (command relationships)
4. Resiliency, redundancy, and hardening plan (physical/long term)
5. Responsive and reliant communications for military/civilian response

Deterrence: Left of Bang

1. Reenergize the DoD to train and exercise Contingency and Emergency communication plans (PACE plan)
   a. Mandate to unify communities w/ EMP plan to include municipal entities, utilities etc.
2. Infrastructure protection
   a. Prioritized list of what industry/power/financial networks need to be hardened—EMP survivability rating?
   b. bIncentivize protected commercial assets that provide military comm services, with sufficient EMP shielding for future satellites
   c. Mandate future asset development with EMI/EMP protection capabilities
   d. Implement micro-power grids according to a prioritized list (regional commands)
   e. Fiber lines, software based radios, laser communications
   f. HF/HAM radio assets with people trained and proficient in TTPs
3. Prepositioned comm assets in EMP facilities or containers
   a. Regional military commands
   b. Data pods in FVEY countries
4. Launch micro-sat system to be repeaters for UHF/VHF/etc. communication
5. Autonomy of decision making (centralized control/decentralized execution—mission type orders)

Recovery

What are our strategic blind spots in regard to EMSO, and how do we counter/frustrate enemy efforts (place near term bets)?

1. Public buy-in and "user pull" with public leaders, military leadership and industry

   a. Lack of investment strategy and civil coordination
   b. Day without EMS
2. No grounded understanding in E1, E2, E3 effects on spectrum of systems and capabilities
   a. Increase modeling and simulation across DOD, industry, academia
3. Execute recovery plans and capabilities across CONUS regions and multi-national
   a. Gain SA of situation
   b. NORTHCOM/DHS cooperative execution of command and control
4. Execute dispersal and positioning of minimum essential equipment list (COOP plan)
   a. Establish communications (NC3 L2 from SAC?); nuclear mobile comm teams, civilian telecommunications
   b. Launch Cube-Sats/micro-sats
5. Expectation management to DOD and civilian sectors
6. Execute prioritized restoration of critical infrastructure

Retaliate

How can industry, academia, and military work together to counter our strategic blind spots and improve the Nation's resilience?

1. Include more industry, energy companies, data analysis personnel in R&D, capability
2. Invest in STEM! Public education baseline must support this fight
   a. Educate the populace through civil defense programs—strengthen will of the people
   b. Take advantage of community relationships w/ mil bases
   c. Benchmark relationships, synergy of investment dollars
   d. Find those civ/mil SMEs and organizations (AFIT, RAND, AF/A9, AF Office of Scientific Research)
3. Develop quantum computing, cognitive EW, and advanced AI to provide I&W and support to attributing responsibility
4. Action on strategic messaging

Track II: HPEM/DE/Spectrum

What sustainable, efficient, and cost-effective approaches do we need to invest in/develop right now to keep Joint Force capability operational (viable) in a severe EMS-degraded environment?

1. Share existing test and mitigation information—reach consensus
2. Identify & prioritize critical infrastructure & defense dependencies
3. Single accountable agency & shared strategy
4. Test, assess, plan, exercise

Strategic blind spots & counter/frustrate enemy efforts (near term)

1. Strategic blind spots
    a. Disagreement on anticipated effects
    b. Inadequate testing and integrated exercises
    c. Lack of national and military strategy and plans
    d. Lack of R&D integration with users and acquisitions
2. Counter/frustrate enemy efforts (near term)
    a. Share existing test information – update environmental standards

Work together to counter our strategic blind spots and improve the Nation's resilience?

1. What roles should industry, academia, and military play?
    a. Team approach – integrated planning and exercises
    b. Differing lanes – natural disasters versus national defense
2. How can the convergence of industry, academic, and military efforts counter strategic blind spots and improve the Nation's resilience?
    a. Incentives/Disincentives for innovation & mitigation
    b. Information sharing among stakeholders
    c. Public outreach programs
    d. Best practices programs

Track III: EMP and GMD

What sustainable, efficient, and cost-effective approaches do we need to invest in/develop right now to keep Joint Force capability operational (viable) in a severe EMS-degraded environment?

1. Investments
    a. Education, Training and Policy/Doctrine
        i. Develop Corporate knowledge and properly capturing historical documents, data, knowledge
    b. Continue effort to identify and harden DoD mission critical infrastructure (black start cap)
    c. Identify and Harden essential infrastructure (power stations, water/sanitation, comms, etc.)
2. Developmental Requirements
    a. Policy/Doctrine/Standards
        i. GOLDEN HOUR standards, drills and exercises (civilian and military)
    b. Hardening standards and testing (tiered solution for Military/Civil/Infrastructure)
    c. Marketing Campaign for response and preparedness
    d. Critical personnel and family plans
    e. Streamlined Acq process (i.e., AFWERX/SOFWERX/Army Futures command like capabilities) CVC

What are our strategic blind spots in regard to each track (EMSO, HPEM/5G/DE, EMP/GMD, and EMS/Quantum) and how do we counter/frustrate enemy efforts (place near term bets)?

1. What are our strategic blind spots?
    a. Adversary Policy and Doctrine for EM Warfare
        i. Adversary Understanding of our Policy and Doctrine for Response/First use
        ii. Adversary views of readiness and vulnerabilities
    b. Identifying, understanding and testing our internal vulnerabilities, gaps, capabilities
    c Inadvertently/knowingly building vulnerabilities with tech advances

   d. Remove barriers for sharing information (classification/political/bureaucratic/Patent process)
2. Prioritize near-term responses to counter/frustrate enemy efforts.
   a. Deterrence/Strategic Messaging/Denial and Deception
   b. Codify achievable requirements for future system design to include EM protection/resilience
   c. EDTF Outreach

How can industry, academia, and military work together to counter our strategic blind spots and improve the Nation's resilience? Conv

1. What roles should industry, academia, and military play?
   a. *Gov/Military set the example with deterrence/resilience
   b. Academia train the next generation of experts
   c. Industry invest/develop incremental hardening plans and technologies
2. How can the convergence of industry, academic, and military efforts counter strategic blind spots and improve the Nation's resilience?
   a. Remove barriers for sharing information (classification/political/bureaucratic)
   b. *Gov/Military/Industry strategically funding/incentivizing resilient systems
   c. *Gov/Military/Academia developing education, training and expertise

***Government=federal/state/local**

Track IV: Quantum/5G Working Group

How resilient is 5G?

1. Not very as it is vulnerable to the effects of EMP just as 4G
2. Mobile network is VERY dependent on power
3. Large Macro-Cell stations may have some emergency power, but small cells are unlikely to have any useful emergency power
4. Existing power grid relies on a SCADA (Survey Control and Data Acquisition) network that for resiliency needs to be independent of the general 5G network

Recommendations

1. Test for effects of EMP against base station infrastructure
2. Retrieve technical inputs on SCADA resiliency

How does 5G relate to computing at the edge?

1. 5G Standards allow the integration of edge computing located at base stations
2. 5G's ability to embed compute services inside mobile network greatly increases the attack surface
3. In severely degraded environment (i.e. EMP), without connectivity to control elements inside the core network, communication ceases

Recommendations

1. Test distributing the core network (if it is possible)
2. Test shutting down network in localized area on the ground, running the network via airborne platform (i.e. UAV)

How does the RF degraded environment affect data retrieval at the edge (i.e. impact to the cloud)?

If the base station is disconnected from the network, then there is no connectivity to the cloud)

What happens when we lose PNT (upon which all transpiration layers are reliant)?

If properly designed, it is possible to communicate timing data via fiber-optic connectivity (rarely done at present)

Additional Quantum/5G Question

How do we establish/preserve/regenerate joint 5G/Quantum Computing capabilities now?

1. Networks need to be China-free
2. Supply Chain integrity
3. Encryption Improvement (zero-trust model for communications)
4. Need more Mid-Band spectrum in commercial service for economies of scale

What are our strategic blind spots in regard to 5G/Quantum?

1. Lack of education of what 5G is, why it affects everyone, and how to harden before emergency
2. US is deploying 5G in different spectrum
3. Unknown interdependencies between power, SCADA, and mobile that may prohibit recovery from HEMP event
4. US telecom providers unaware of viability of EMP

How can industry, academia, and military work together to address these strategic blind spots?

1. Formally recognize EMS as a domain
2. Establish training within services for EMS scenarios (total force training)
   a. Educate—EMS should be taught at entry level training and up (e.g. OTS and BMT). Strategic thinking with regard to EMS should start much younger than where we are now.
   b. Train—on basic and continuation training/at unit-directed level
   c. Evaluate—define operational metrics (msn/people) to determine if training is effective
3. Train industrial base on significant risks
4. Lower level recruitment (whole-of-society efforts)
   a. Set up something similar to Palace Acquire (sets career path for recruited STEM grads)
   b. Create programs for younger kids, not just college grads; not just recruiting into the military—develop civilian/reserve option
   c. Define what we want the future to be and work toward it
5. DoD needs to plan for operations in a post-Western Internet environment

How can we organize, train, equip, and provide for each strategy?

1. Organize: create linkages between AETC and internal and external orgs (e.g. AFRL linking with AETC); tap into UARC/EWI; develop new process/policy for spectrum collaboration/sharing (whole-of-society efforts)
2. Train: ensuring every Airman understands EMS and becomes responsible as a stakeholder in protection of EMS (strategic thinking at all levels); create operational exercises with real life impact (e.g. two days post-IOS update shut down all without update); strengthen red team capability/feedback AF wide
3. Equip/provide: right equipment to accomplish msn; determine level of hardening based on msn

We should develop a DOTMLPF-P for a national response framework to a HEMP scenario that pre-plans federal/state responsibilities, details evacuation plans for large cities to simplify resupply efforts, reassess existing utility of organizations like the Civil Air Patrol, and ensure an effective, high-bandwidth emergency communication systems that integrates all elements

What do we need to invest in/develop to implement the strategy?

1. Invest: Sub-6 technology vs mmWave; buy and test (e.g. OSD Foreign Comparative Testing Office);
2. Develop: Cooperative model to test/evaluate 5G/Quantum (including academia, industry, and specific foreign partners)
3. Terrestrial Alternative to GPS; 5G/Quantum can assist with providing high-precision timing to ensure that there is an alternative to GPS should the satellite system be inaccessible due to ionization

Are quantum communications resilient to EMS?

Theoretically, quantum communications *should* be more resilient; more research is needed.

Appendix 6

List of Attendees and Contacts

This appendix is a sample list of more than 100 agencies represented at the 2019 Electromagnetic Defense Task Force summit.

- Air Education and Training Command
- Air Force Civil Engineering Center
- Air Force Global Strike Command
- Air Force Institute of Technology
- Air Force Materiel Command
- Air Force Research Laboratory
- Air Force Special Operations Command
- Air University
- Alabama Rural Electric Association
- Argonne National Laboratory
- Defense Innovation Board
- Defense Spectrum Organization
- Defense Threat Reduction Agency
- Department of Homeland Security
- Federal Energy Regulatory Commission
- George Mason University
- Georgia Tech Research Institute
- Idaho National Laboratory
- IHS Markit
- Johns Hopkins University
- Joint Chiefs of Staff (Joint Staff)
- *Journal of Electronic Defense*
- Lockheed Martin
- Los Alamos National Laboratory
- National Aeronautics and Space Administration (NASA)

- National Defense University
- North Atlantic Treaty Organization (NATO)
- Nuclear Regulatory Commission (NRC)
- Office of the Secretary of Defense
- Royal Australian Air Force
- Royal Australian Navy
- Sandia National Laboratory
- Southwest Research Institute
- State of Alabama, Governor's Office
- Texas State House of Representatives
- Texas State Office of Risk Management
- The Curtis E. LeMay Center for Doctrine Development and Education
- The White House
- Union of Concerned Scientists
- United States Strategic Command
- University of Colorado
- University of Texas
- Wyoming National Guard

Appendix 7

EMS Resilience and Preparedness for Government and Society

Background

During the Electromagnetic Defense Task Force (EDTF) 2.0, a fellow with more than 33 years of uniformed service provided a historic reflection demonstrating the importance of assuring the protection of civilians and supporting civil infrastructure to ensure mission accomplishment. The fellow had been part of the first operational readiness exercise conducted by Strategic Air Command (SAC) in 1964, when Gen Curtis LeMay was vice chief of SAC. During the exercise, conducted in Minot AFB, North Dakota, with an outside temperature of 20 below zero, General LeMay turned off all the power to the base housing area. Not a single aircraft was able to get airborne due to the number of military personnel who stayed home to tend to their families.

A 2019 exercise at Fort Bragg, North Carolina, led to similar outcomes. During the exercise, a mock cyberattack induced a blackout of approximately 12 hours in conjunction with the exercise deployment of an Army Airborne Division, "to test the community's ability to rebound from an attack and still get troops off on their mission."[1] The half-day exercise resulted in sufficient turmoil from the local civilian and military population that the installation issued an apology and the garrison commander's office had to coordinate with the post's judge advocate general to assist residents with claims for losses caused by the exercise-induced blackout. This contemporary exercise demonstrates that the criticality of residential and family resilience has not changed since LeMay's 1964 exercise.

With these exercises as a contextual backdrop, EDTF experts explored modern cultural resilience, the human psychological dimension of a long-term electric grid collapse, and existing US government guidance on resilience and preparedness associated with electromagnetic spectrum (EMS) threats. The discussion produced several insights that are presented below.

1. Meghann Myers, "You Can Claim Damages if the Fort Bragg Power Outage Ruined Your Stuff," Army Times, 2 May 2019, https://www.armytimes.com/news/your-army/2019/05/02/you-can-claim-damages-if-the-fort-bragg-power-outage-ruined-your-stuff/.

Federal Guidance on EMS Resilience and Preparedness

The Department of Homeland Security's (DHS) 5 February 2019 release *Electromagnetic Pulse (EMP) Protection and Resilience Guidelines for Critical Infrastructure and Equipment* is the most recent authoritative document dealing with the resilience and preparedness specifically associated with EMS threats. It describes four EMP protection levels for infrastructure and equipment that underscore the importance of food, water, and critical supplies and spares to assure the human sustainment and health.

While the DHS resource is informative about infrastructure protection and associated costs of EMS threat mitigation, it does not provide recommendations or cost estimates associated with the storage of food, water, or critical supplies that may be required to support military personnel or their families. Nevertheless, DHS's focus on a 30-day period of preparedness corresponds to the EDTF 1.0 consensus view that 30 days of food and water is a reasonable and realistic target to ensure the families of military personnel are sustained during a prolonged power outage. However, it was noted during Federal Emergency Management Agency's (FEMA) National Preparedness Symposium in 2018 that "current [FEMA] planning does not include any contingencies for very long or extremely widespread power outages."[2]

Furthermore, the National Infrastructure Advisory Council's (NIAC) December 2018 report, titled "Surviving a Catastrophic Power Outage: How to Strengthen the Capabilities of the Nation," contained a recommendation to "develop guidance and provide resources for states, territories, cities, and localities to design community enclaves—areas that colocate critical services and resources to sustain surrounding populaces, maintain health and safety, and allow residents to shelter in place." A subtask recommended the following: "Identify the critical lifeline functions that communities need (even in a limited capacity or degraded state)—such as communications, electricity, fuel, limited financial services, food, water and wastewater, and medical facilities—and for how long (i.e., 30–45 days)."[3]

In its specific analysis on the topic of individual preparedness, the NIAC report provides examples of state government initiatives for community

2. Lonnie Lawson, Brenda Vossler, and William Byrd, "Private and Public Cyber Security Issues in Rural America" (PowerPoint presentation, National Preparedness Symposium, Anniston, AL, 24 May 2018), https://training.fema.gov/nationalpreparednesssymposium/_assets/2018/2018%20private%20&%20public%20cyber%20security%20issues%20in%20rural%20america.pptx.

3. The President's National Infrastructure Advisory Council (NIAC), *Surviving a Catastrophic Power Outage*, December 2018, 11, www.dhs.gov/sites/default/files/publications/NIAC%20Catastrophic%20Power %20Outage%20Study_508%20FINAL.pdf.

preparedness and references three states (Washington, Oregon, and Hawaii) that encourage citizens to maintain a 14-day supply of essentials.[4]

Consequences to Government and Society from an EMS Attack

EDTF is assessing existing data pertaining to EMS threats and the effects such threats could have on government and society. Since adversaries exploiting EMS would likely focus attack(s) to cause the most widespread and long-term damage, EDTF experts specifically explored the human dimension of life without electricity, examined existing government-sponsored reports on this topic, and invited the participation of subject matter experts in this area.

According to research conducted by the US Congress's EMP Commission, there is an assumption that an EMP-induced blackout could cause a long-term nationwide grid collapse and the loss of up to 90 percent of the population through starvation, disease, and societal collapse. While this mathematical assessment is based on population metrics, it is not without debate. However, the basis of this calculation is not unreasonable from a logistics standpoint. America is no longer the benefactor of widespread off-grid farming or nonelectric farming equipment. In 1820, farmers made up approximately 72 percent of the US population.[5] Today, only about 2 percent of the US population works in agriculture.[6] The ability to continue providing food to approximately 165 million people with a 70 percentage point drop in farming is enabled through large-scale, computer-controlled, just-in-time farming operations. Such operations rely on computers, the internet, access to large-scale commercial trucking logistics, distribution algorithms, open lines of communication between the various stakeholders, and access to fuel—all of which rely on the nation's interconnected commercial power grid.

One of the experts invited to participate in this discussion was Jonathan Hollerman, a former USAF SERE (survival, evasion, resistance, and escape) instructor. He was asked to provide his perspective on this topic of how a long-term blackout would affect the American populace and, specifically, the US military.

Hollerman's informed analysis focused on three overarching factors that he suggests are absent in most government-sponsored plans: (1) human desper-

4. NIAC, *Surviving*, 13.

5. Associated Press, "Farm Population Lowest since 1850s," *New York Times*, 20 July 1988, https://www.nytimes.com/1988/07/20/us/farm-population-lowest-since-1850-s.html

6. "Fast Facts about Agriculture," American Farm Bureau Federation, accessed 22 July 2019, https://www.fb.org/newsroom/fast-facts.

ation, (2) starvation, and (3) living without rule of law (WROL).[7] Hollerman's work is his own professional assessment/opinion and not reflective of an official position of EDTF or its fellows; however, it does evoke an understanding of the potentially troubling consequences of a long-term, nationwide blackout and emphasizes the reality that America must secure its critical national infrastructure against EMS threats.

A Way Forward

EDTF 2.0 began the preliminary process of generating strategies that could be applied to enhance EMS resilience and preparedness for government and society. Strategies ranged from encouraging citizens to stock larger quantities of food, water, and basic supplies to encouraging gas stations to maintain backup generators to pump fuel to the EMS hardening of municipal water and wastewater systems.

EDTF will continue to focus on generating sensible recommendations in the area of emergency management, consequence management, continuity of operations, and food and water resilience with three goals in mind:

1. Identifying and expanding the array of technological assets and physical measures that can be applied to infrastructure and equipment to increase EMS resilience.
2. Identifying the best way to prioritize these measures to increase survivability and resilience of society and government personnel and organizations.
3. Identifying methods of incentivizing governmental organizations as well as the owners and operators of life-sustaining infrastructures to make their assets resilient to EMS threats and their personnel (and families) more capable of maintaining health and welfare in an EMS-degraded environment.

7. Jonathan Hollerman, *Grid Down: Death of a Nation* (self-pub., 2019), https://www.griddownconsulting.com/grid-down-report.

Abbreviations

Abbreviation or acronym	Spelled out form of term or organization
ACC	Air Combat Command
AER	Atmosphere and Environmental Research
AEMA	Alabama Emergency Management Agency
AETC	Air Education and Training Command
AFIT	Air Force Institute of Technology
AFLCMC	Air Force Life Cycle Management Center
AFRL	Air Force Research Lab
AFSPC	Air Force Space Command
AFWIC	Air Force War-fighting Integration Capability
AGC	automatic generation control
AI	artificial intelligence
APNSA	Assistant to the President for National Security Affairs
ARRL	American Radio and Relay League
ATSO	ability to survive and operate
AU	Air University
BDBE	beyond-design-basis event
BDBEE	beyond-design-basis external event
BIL	basic impulse level
BMT	basic military training
BST	Black Start team
CCMG	Continuity Communications Managers Group
CISA	Cybersecurity and Infrastructure Security Agency
CME	coronal mass ejection
COA	course of action
COE	center(s) of excellence
CONUS	continental United States
COOP	continuity of operations
CSAF	chief of staff, United States Air Force

CVC	combat vehicle crewman (helmet)
DBT	design basis threat
DE	directed energy
DEVOP	developers and operations
DHS	Department of Homeland Security
DIB	Defense Innovation Board
DIME	diplomatic, informational, economic, and military
DOD	Department of Defense
DOE	Department of Energy
DOTMLPF-P	doctrine, organization, training, materiel, leadership and education, personnel, facilities, and policy
DPR	digital protective relays
DSB	Defense Science Board
ECCT	Enterprise Capability Collaboration Team
ECD	Emergency Communications Division
EDG	emergency diesel generators
EDTF	Electromagnetic Defense Task Force
EHV	extra high voltage
EM	electromagnetic
EMBM	electromagnetic battle management
EME	electromagnetic environment
EMI	electromagnetic interference
EMP	electromagnetic pulse
EMS	electromagnetic spectrum
EMSO	electromagnetic spectrum operations
EPRI	Electric Power Research Institute
EW	electronic warfare
FAA	Federal Aviation Administration
FCC	Federal Communications Commission
FEMA	Federal Emergency Management Agency
FERC	Federal Energy Regulatory Commission
FVEY	Five Eyes

GDP	gross domestic product
GIC	geomagnetically induced current
GMD	geomagnetic disturbance
HAF	Headquarters Air Force
HEMP	high-altitude electromagnetic pulse
HF	high frequency
HPEM	high-powered electronics and microwaves
IADS	Integrated air defense systems
IEC	International Electrotechnical Commission
IEMI	Intentional Electromagnetic Interference
IOS	internetwork operating system or internet operating system
IoT	internet of things
ISR	intelligence, surveillance, and reconnaissance
JEMSO	Joint Electromagnetic Spectrum Operations
L2	lessons learned
LVC	live, virtual, and constructive
M&S	modeling and simulation
MAJCOM	major command
MARS	Military Auxiliary Radio System
MDC2	multi-domain command and control
NAOC	National Airborne Operations Center
NC3	nuclear command, control, and communications
NCC	National Coordinating Center for Communications
NDS	National Defense Strategy
NERC	North American Electric Reliability Corporation
NIAC	National Infrastructure Advisory Council
NMCA	National Military Command Authority
NPP	nuclear power plant
NRC	Nuclear Regulatory Commission
NSS	National Security Strategy
OPFOR	opposing force(s)

OSD	Office of the Secretary of Defense
OT/DT	operational testing/developmental testing
OTS	officer training school
PACE	primary, alternate, contingency, emergency
PNT	positioning, navigation, and timing
POTUS	president of the United States
PTN	Pilot Training Next
R&D	research and development
RF	radio frequency
ROMO	range of military operations
SBO	station blackout
SCADA	supervisory control and data acquisition
SCADAS	supervisory control and data acquisition systems
SERE	survival, evasion, resistance, and escape
SFP	spent fuel pool
SPECTRE	Specialized Electronic Combat and Reprogramming Environment
SSA	Sector-Specific Agency
STEM	science, technology, engineering, and mathematics
T&E	test and evaluation
TTX	tabletop exercise
TVA	Tennessee Valley Authority
UARC	university affiliated research center(s)
UAV	unmanned aerial vehicles
UHF	ultrahigh frequency
UPS	uninterrupted power supply
USG	United States government
USNORTHCOM	US Northern Command
USSTRATCOM	US Strategic Command
VHF	very high frequency
WROL	without rule of law

AIR UNIVERSITY PRESS

https://www.airuniversity.af.edu/AUPress/

ISSN 2575-6737
LP-4

NREL

Emergency Diesel Generator Reliability and Installation Energy Security

Jeffrey Marqusee, Sean Ericson, and Don Jenket

National Renewable Energy Laboratory

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Contract No. DE-AC36-08GO28308

Technical Report
NREL/TP-5C00-76553
April 2020

Emergency Diesel Generator Reliability and Installation Energy Security

Jeffrey Marqusee, Sean Ericson, and Don Jenket

National Renewable Energy Laboratory

Suggested Citation
Marqusee, Jeffrey, Sean Ericson, and Don Jenket. 2020. *Emergency Diesel Generator Reliability and Installation Energy Security*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5C00-76553. https://www.nrel.gov/docs/fy20osti/76553.pdf.

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Contract No. DE-AC36-08GO28308

Technical Report
NREL/TP-5C00-76553
April 2020

National Renewable Energy Laboratory
15013 Denver West Parkway
Golden, CO 80401
303-275-3000 • www.nrel.gov

NOTICE

This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Support for the work was also provided by the Department of Defense's Environmental Security Technology Certification Program (ESTCP) under Agreement IAG-18-02080. The views expressed herein do not necessarily represent the views of the DOE or the U.S. Government.

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

U.S. Department of Energy (DOE) reports produced after 1991 and a growing number of pre-1991 documents are available free via www.OSTI.gov.

Cover Photos by Dennis Schroeder: (clockwise, left to right) NREL 51934, NREL 45897, NREL 42160, NREL 45891, NREL 48097, NREL 46526.

NREL prints on paper that contains recycled content.

List of Acronyms

DER	distributed energy resource
DoD	U.S. Department of Defense
EDG	emergency diesel generator
FTS	failure to start
IEEE	Institute of Electrical and Electronics Engineers
MTBF	mean time between failure
MTTF	mean time to failure
MTTM	mean time to maintain
MTTR	mean time to repair
NRC	Nuclear Regulatory Commission
NREL	National Renewable Energy Laboratory
OA	operational availability
PREP	U.S. Army Corps of Engineers Power Reliability Enhancement Program
SCADA	Supervisory Control and Data Acquisition

Executive Summary

The U.S. Department of Defense's (DoD's) fixed installations—or military bases—are a critical element of national security. Military bases support the maintenance and deployment of weapons systems, training and mobilization of combat forces, and provide direct support to combat operations. They also play a critical role in homeland defense and during domestic emergencies by providing support to civil authorities. Fixed installations do not operate without energy and they rely largely on electricity to support critical missions and functions. Installations are dependent on a commercial grid that is vulnerable to disruption due to severe weather, physical attacks, and cyberattacks.

The current default solution for backup energy at military installations relies on emergency diesel generators (EDGs). This is most often accomplished by either a single stand-alone generator or two generators tied to an individual building with critical loads. Less commonly, but with increasing frequency, diesel generators are networked and serve as the primary distributed energy resource for a microgrid. EDGs can fail more often than recognized and their reliability must be considered when evaluating energy backup system architectures. This report provides an analytic approach to quantitively assess the impact of an EDG's reliability on both stand-alone building tied systems and microgrids.

Based on a new analysis of existing empirical data, Figure ES- 1 shows the reliability of an EDG as a function of outage duration and level maintenance. A well-maintained EDG is one that rigorously follows Unified Facility Criteria guidance (UFC 3-540-07). A poorly maintained EDG is unlikely to provide power for durations longer than a few days and has a reliability of only 80% at 12 hours. This figure reinforces the importance of following the current guidance on EDG maintenance. But even well-maintained EDGs have a reliability of only 80% at two weeks. Thus, a single well-maintained EDG cannot guarantee emergency power for critical loads over multiday outages.

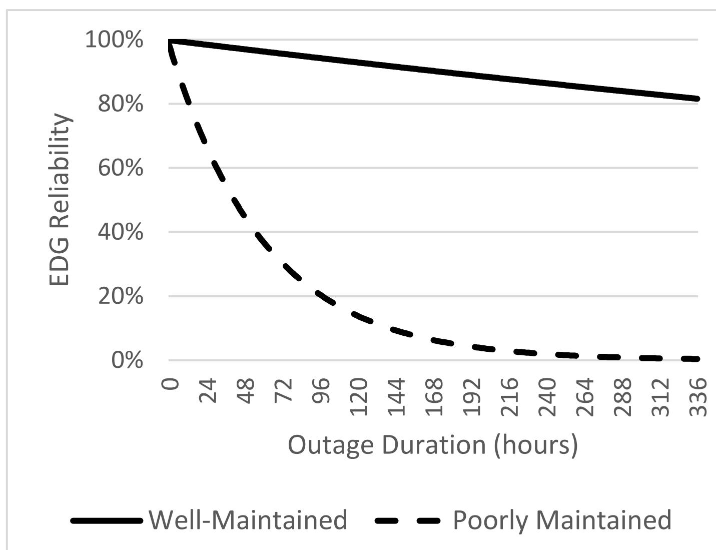


Figure ES- 1. The reliability of a single EDG over two weeks (336 hours)

Calculations of the reliability of different backup energy architectures for four model installations are provided (see Table ES- 1). The installation energy scenarios include a range of critical load sizes typically found on military installations and realistic hourly load profiles. The scenarios include outages ranging from one hour to two weeks and cover typical conditions found on small national guard and reserve bases up to very large domestic active military installations. These scenarios can serve as screening level benchmarks for the expected performance on fixed installations worldwide. The tool to assess backup power system reliability is available, through the National Renewable Energy Laboratory (NREL), for site-specific assessments to evaluate current energy assurance performance and potential future alternative systems.

Table ES- 1. Annual Hourly Peak Critical Load, Number of Critical Buildings for the Small, Medium, Large, and Very Large Bases Sizes Modeled

Base	Small	Medium	Large	Very Large
Peak Annual Critical Load (MW)	1	5	10	20
# Buildings With Critical Loads	8	40	80	160

Three base level reliability metrics (probability of supporting 100% of critical load, fraction of lost load, and probability to satisfy the highest priority critical loads) are examined for well-maintained EDGs. Poorly maintained generators do not meet the needs of military installations independent of how they are arranged. Even in a microgrid configuration, the loss of multiple generators within a few days due to poor maintenance yields inadequate performance.

The probability that all critical load will be 100% supported as a function of outage duration up to two weeks is shown below for the small and very large base. The performance of two systems are shown; a microgrid with N+1 back-up generators (referred to as an N+1 microgrid) where N generators are needed to satisfy the annual peak critical load, and a system where one EDG is tied to each building.

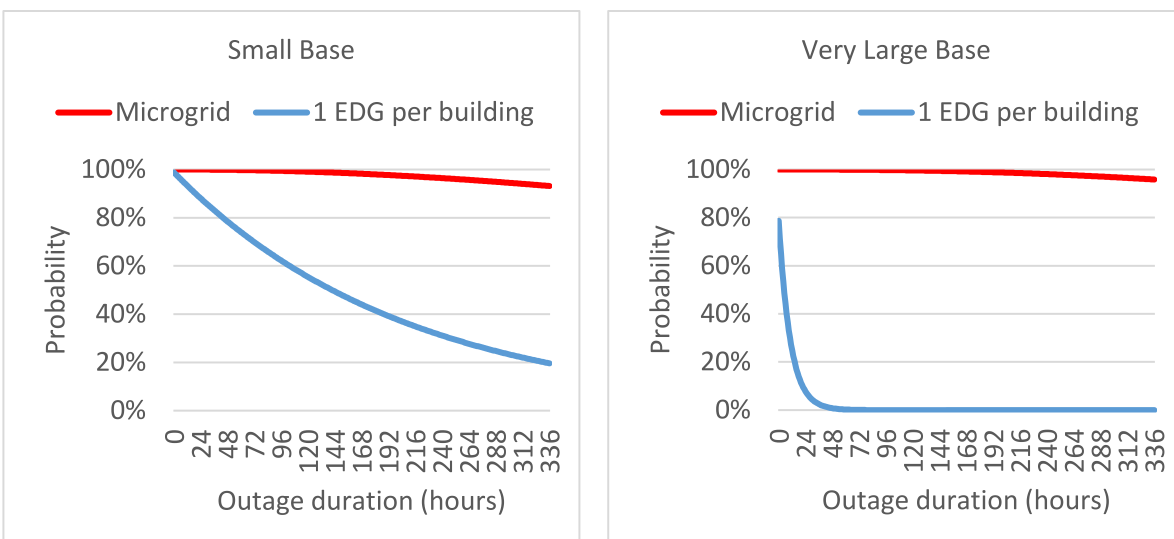


Figure ES- 2. The probability of an N+1 microgrid and a single EDG per building architecture meeting 100% of the critical load requirement for outages up to 14 days (336 hours). For small (left) and very large (right) bases.

Due to the ability of EDGs to share load in a microgrid, this architecture maintains a high probability of meeting a 100% of the critical load for two weeks for all bases. Stand-alone generators have a small probability of providing power for all buildings with a critical load for a multiday outage.

Table ES- 2 shows the 90% confidence intervals for the fraction of lost load for the N+1 microgrid configuration and the fraction of buildings without power for a single stand-alone EDG per building for outages of 7 and 14 days for all four bases. The fraction of buildings without power in a stand-alone system is independent of the size of the base.

Table ES- 2. 90% Confidence Ranges for the Fraction of Load a Microgrid Must Shed and the Fraction of Buildings with Critical Load That Will Not Have Power if One Uses a Single Stand-Alone Building-Tied EDG at 7 and 14 Days

Architecture	Microgrid	Microgrid	Microgrid	Microgrid	Stand-Alone
Bases	Small	Medium	Large	Very Large	All
7 days	0.1% - 0.7%	0.0% - 0.2%	0.0% - 0.2%	0.0% - 0.2%	7% - 13%
14 days	0.7% - 3.4%	0.2% - 1.5%	0.2% - 1.5%	0.2% - 1.7%	13% - 25%

In the microgrid case, the loss of generation can be managed by shedding lower priority critical loads to maintain the microgrid's stability. In the case of building-tied systems, no action can compensate for the EDGs' failures.

Finally, we look at the impact on the highest priority critical loads, typically only a fraction of the total critical load. These are loads that are required to support high priority critical missions that must be sustained. For this case, we will compare an N+1 microgrid architecture to two EDGs per building. Figure ES- 3 below shows the probability of meeting the highest priority load for situations where the high priority load is 25% of the total critical load for a microgrid and for the two stand-alone EDGs per building. The microgrid essentially has a 100% probability because it can prioritize which loads are the most important and preferentially send power to those loads. Stand-alone building-tied systems, even when two EDGs are tied to each building, cannot provide high confidence that the highest priority loads will be supported.

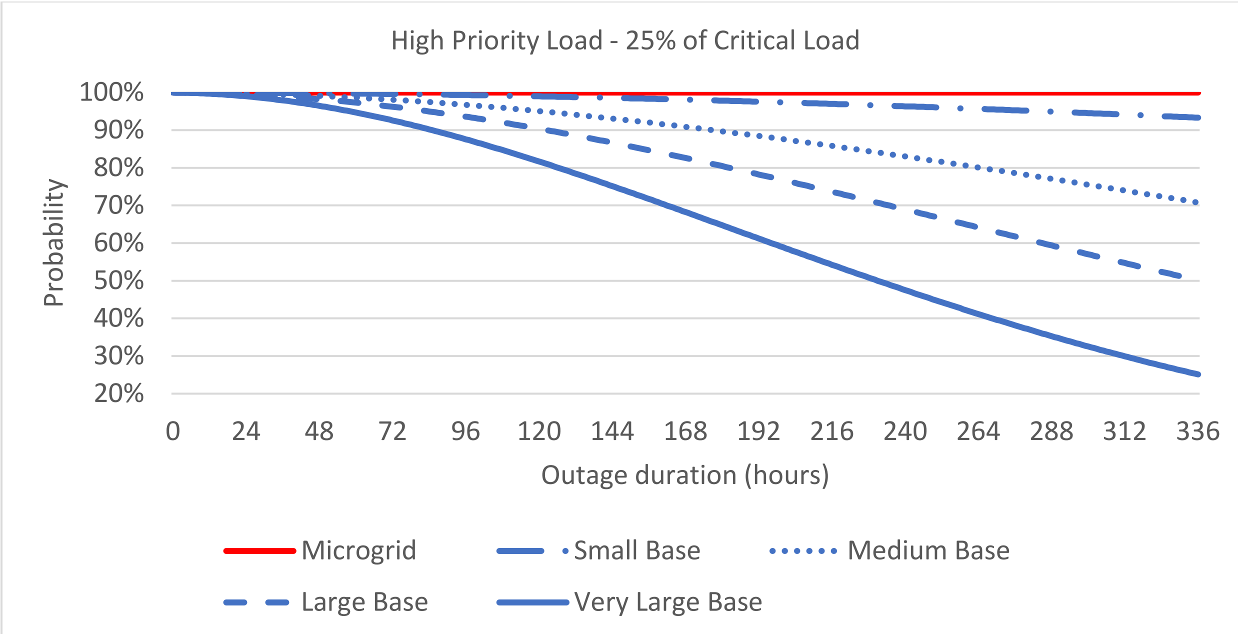


Figure ES- 3. Probability of meeting 25% of highest priority critical load for small, medium, large, and very large bases. Building-tied systems are shown in blue and microgrids are shown in red. Building-tied systems have two EDGs per building and microgrids for all size bases overlap.

All three metrics provide overwhelming evidence that stand-alone building-tied EDG systems, even when two EDGs are used, cannot provide the level of confidence required by DoD installations for power to be available to support critical missions during a multiday grid outage. Diesel generator based microgrid configurations provide a robust source of power for critical loads due to their network configuration and ability to share load. But microgrid architectures do introduce other vulnerabilities that must be managed, including cyber vulnerabilities and dependence on the on-base distribution system.

Emergency diesel generators must be well-maintained if they are to be relied on for providing power longer than a few hours. If backup power is required for multiple days, stand-alone building-tied emergency diesel generators cannot be relied on by themselves to provide backup power for critical loads, and a microgrid should be considered.

Table of Contents

List of Figures

List of Tables

1 Introduction

1.1 Background

The U.S. Department of Defense's (DoD's) fixed installations—or military bases—are a critical element of national security (1). Military bases have long supported the maintenance and deployment of weapons systems and the training and mobilization of combat forces. Increasingly, they perform direct support to combat operations. They also play a critical role in homeland defense and during domestic emergencies can provide support to civil authorities. Today they cannot be assumed to be free from threats; as the recent National Defense Strategy (2) noted, "the homeland is no longer a sanctuary."

Fixed installations cannot operate without energy and they rely on electricity to support critical missions and functions. DoD's fixed installations consumed more than 200,000 billion[1] BTUs in 2018 (3). The military's use of facility energy carries a hefty price tag: DoD's utility bill is almost $4 billion per year. But more important for the military's mission is its reliance on energy entails operational risk as well as cost.

Installations are dependent on a commercial grid that is vulnerable to disruption due to severe weather, physical attacks, and cyberattacks. Power outages are a fact of life. Outages can range in duration from minutes to weeks, and their impact can be geographically limited (a failure in a single feeder line) or widespread (a failure in the bulk transmission system that affects hundreds of thousands of people in multiple states). The risks of blackouts and loss of electric power are not new. Outages of just a few hours are well known, but longer duration outages are becoming more frequent (4). In the United States, these outages are driven by an increasing frequency and intensity of severe storms (thunderstorms, blizzards, hurricanes, and other high-wind events), fires, and increased load demand and strain due to extreme temperature events, including heat waves and polar vortices. These outage threats are increasing due to climate change and unlikely to return to historical norms in the future.

In addition to natural hazards, the commercial grid is vulnerable to manmade threats, both physical and cyber. The fastest growing threat to the electric grid is cyberattacks, in which hackers try to manipulate industrial control and Supervisory Control and Data Acquisition (SCADA) systems to disrupt the flow of electricity. Energy infrastructure has become a major target of cyberattacks (5). More frequent and sophisticated attacks are likely from both nation-states and cyber criminals.

The current default solution for energy assurance and resiliency at military installations relies on emergency diesel generators (EDGs). This is most often accomplished by either a single stand-alone generator or two generators tied to an individual building. Less common, but with increasing frequency, diesel generators are networked and serve as the primary distributed energy resource (DER) for a microgrid. [redacted] In the absence of such information, military installations cannot quantitively assess their current energy assurance vulnerabilities nor evaluate alternative approaches. Furthermore, as more advanced solutions

[1] This includes both electricity and natural gas.

involving renewable energy generation and storage evolve, reliability information is required for the current baseline approaches to assess the value of these new solutions.

1.2 Scope of Study

The National Renewable Energy Laboratory (NREL) was tasked by DoD's Environmental Security Technology Certification Program[2] (ESTCP) to develop the information and methodology required to quantify the reliability of EDGs and their impact on the effectiveness of backup power systems being deployed on DoD installations. This report documents the results of that effort.

A comprehensive review of the reliability data literature for both emergency and nonemergency diesel generators was conducted. Based on existing data sets, a new set of reliability probabilities and metrics were developed for the EDGs commonly used on DoD's fixed installations. A technical review of existing methodologies for calculating the probability for a system of diesel generators to meet critical load requirements during outages of various lengths was conducted. Based on the limitations of existing methodologies, a new method was developed that provides predictions for the reliability of systems of EDGs.

A set of scenarios was developed for military installations, and the resulting energy reliability was calculated. The installation energy scenarios include a range of critical load sizes typically found on military installations and realistic hourly load profiles. The scenarios include outages ranging from one hour to two weeks and cover typical conditions found on small national guard and reserve bases up to very large domestic active military installations. These scenarios can serve as screening level benchmarks for the performance expected on fixed installations worldwide. The tool used for this analysis is available, through NREL, for site-specific assessments to evaluate current energy assurance performance and potential future alternative systems.

This study's results have three limitations that should be recognized. All these limitations can be addressed but require site-specific information. First and foremost is the impact of the reliability of the on-base electric distribution system. Outages due to failures in the on-base distribution system will directly impact the performance of a microgrid system. They also impact a base's energy resiliency for standalone generator systems as they can increase the frequency of outages. Reliability of the on-base distribution system can be considered but requires site-specific information and is not generalizable from one installation to another. Second is the direct destruction of generators due to flooding or other physical disturbances. This can be avoided by smart planning and depends on the location of the generators and the local risk of flooding or other physical disturbances. Third is the impact of fuel storage and distribution. Diesel generators require fuel to operate. Lack of availability due to finite storage or limited resupply can curtail a generator-based system. Also, moving fuel from a central storage area to individual generators is limited by manpower and available transportation. This can be a significant constraint at a large installation that uses stand-alone generators. All these site-specific issues can be modeled if the site-specific information is available.

[2] Information on the Environmental Security Technology Certification program can be found at https://www.serdp-estcp.org/

2 Installation Energy Assurance

2.1 DoD Energy Policy

DoD's energy policy[3] is "to enhance military capability, improve energy security and resilience, and mitigate costs in its use and management of energy." This policy applies to military bases. It is further articulated in DoD's Installation Energy Management instruction.[4] The instruction states that DoD components "shall take necessary steps to ensure energy resilience on military installations. DoD Components shall plan and have the capability to ensure available, reliable[5], and quality power to continuously accomplish DoD missions from military installations and facilities." The instruction further states that the components "shall clearly define, identify, and update critical energy requirements that align to critical mission operations in collaboration with tenants, mission owners, and operators of critical facilities on military installations." Thus, it is a requirement for all military bases to insure they have reliable backup power needed to carry out their critical missions. DoD's policy also explicitly states that "Energy resilience solutions are not limited to traditional standby or emergency generators." Up to now, military installations have lacked the tools and information to quantify "reliable" power. This study addresses that key need for systems comprised of stand-alone generators or microgrid configurations dependent on EDGs.

2.2 Current Practice

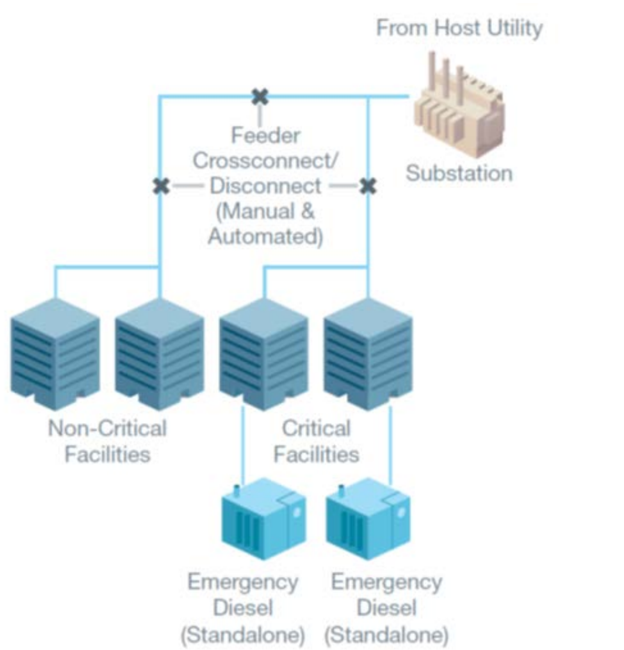


Figure 1. Historical approach—stand-alone generators tied to individual buildings

Stand-Alone Emergency Diesel Generators: DoD has historically relied on stand-alone generators with short-term fuel stockpiles to provide emergency backup power for buildings with critical loads. At every building housing a critical load, a single (stand-alone) backup generator is

[3] Energy Policy DODD 4180.01 August 2018.
[4] Installation Energy Management DODI 4170.11 August 2018.
[5] Emphasis added.

hardwired directly to the building. For the highest priority critical loads, two stand-alone backup generators can be deployed to provide a backup to the backup and a higher degree of reliability. Backup generators found on fixed installations are powered by diesel fuel. A base typically has a centrally managed diesel fuel stockpile that contains enough fuel to allow the generators to run for two to seven days. Figure 1 provides a simplified graphical representation of such a system.

Stand-alone generators on a base are diverse and numerous. They can range in size from 10 kW to 100s of kWs. Because the generators are disconnected from one another, each is sized to meet a building's peak load. DoD guidance directs generators to be sized at twice the current engineering estimate for their peak load (oversizing accommodates the uncertainty in the engineering estimate and possible increases in the building's future load). In practice, they are often sized even larger (1).

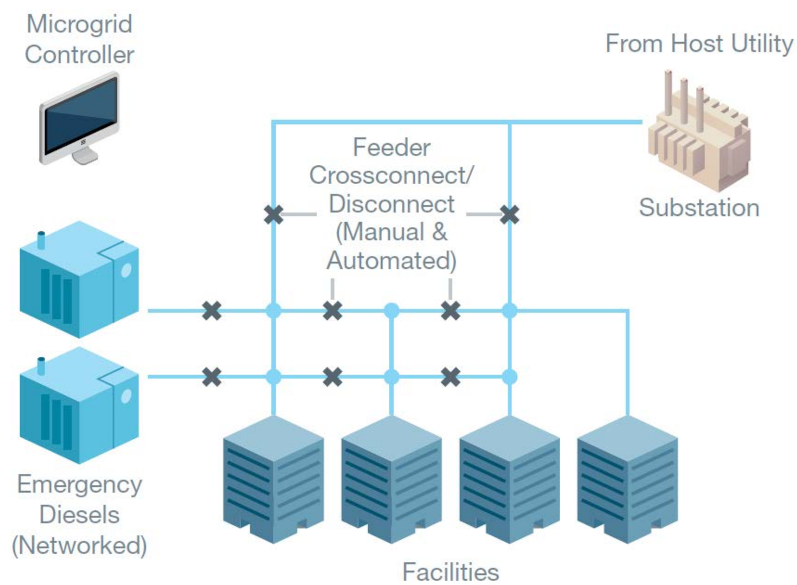


Figure 2. Microgrid with larger networked generators

Microgrid Approach: A microgrid is an alternative way to provide resilient power to a military base. A microgrid is a local system of DERs and electrical loads that can operate as a single entity either in parallel to the commercial (macro) grid or independently (e.g. in "island" mode). Benefits include being used to provide emergency backup power during commercial grid outages or being a source of revenue and savings when connected to the grid. Any on-site power source can serve as a DER, including emergency generators, prime generators, combined heat and power plants, renewables, batteries and other forms of energy. Figure 2 provides a simplified graphical representation of such a system.

Microgrids and stand-alone generators have multiple performance differences (1). There are five key performance criteria that should be considered when assessing the relative value of each system for a specific installation. They are:

1. *Reliability*—A measure of the likelihood that the critical loads will be supported for a required duration during a grid outage. Stand-alone generators lack N + X reliability,

where X is the number of independent backups to the first line of defense (stand-alone), which leads to an inherent limited reliability. A microgrid can readily provide a high level of reliability (N+1, N+2, or more) because the networked structure ensures that if any single generation asset fails, another one can instantly take its place, and it takes little additional backup power to provide even greater reliability.

2. *Flexibility*—A system's ability to accommodate changes in the military's electric power needs both during an outage and over longer time periods. Because stand-alone generators are hardwired to the buildings, they can only supply power to that building; the process of moving one to a new location is costly and time-consuming, requiring decommissioning, transport, and recommissioning. Because microgrids are networked, they can respond to changes in electricity needs at little cost as missions change and requirements evolve.

3. *Coverage*—A system's ability to extend backup power beyond critical loads. Certain intermediate loads both on-base and off-base could advance the mission during an emergency if they had backup power, and some critical loads could get by without a 24/7 level of protection. The reliance on stand-alone generators forces operators to make an "all or nothing" decision: critical loads get 24/7 backup power, and other loads get no backup power. Because a microgrid is at a minimum sized to meet the annual critical peak loads of a base, excess generation is almost always available and can serve any load to which the microgrid is connected, including those loads whose priority falls between "critical" and "noncritical."

4. *Dependence on Distribution System*—On-base electric distribution systems can fail leading to local outages. Stand-alone generators are not directly impacted by these failures; however, system-level failures lead to an increased need for the stand-alone generator to function and thus do increase the impact of potential failures of the stand-alone generators. Microgrids are dependent on the on-base distribution system to supply power to critical loads.

5. *Vulnerability to Cyberattacks*—Stand-alone generators are not required to be networked to any communication system and thus are not vulnerable to a cyberattack. Microgrids depend on an on-base communication system and may be linked to external networks if participating in some off-base electricity markets. Thus, they are susceptible to cyberattack like any other DoD network.

Table 1 provides a summary of these performance criteria for stand-alone generators and microgrids.

Table 1. Stand-Alone and Microgrid Performance Criteria

Criteria	Stand-Alone	Microgrid
Reliability	• Moderate-to-poor reliability	• Readily provides a high level of reliability (N+1 or more)
Flexibility	• No ability to meet changing requirements	• Can respond to changes in mission needs and priorities
Coverage	• Covers critical loads only	• Can cover critical and intermediate loads
Distribution Dependence	• Independent of on-base distribution system	• Vulnerable to failures in on-base distribution system
Cyber Vulnerability	• Isolated from communication network	• Vulnerable to cyberattack

3 Component Reliability

In this section we discuss the reliability of a single EDG (6). We first provide a brief introduction to reliability concepts. Then we describe the relevant metrics to quantitatively represent an EDG's reliability. Next, we review the existing empirical data on EDG performance and conclude by providing the mean reliability and uncertainty of an individual EDG's reliability.

3.1 Reliability Introduction

"Reliability is the probability that the item will perform its required function under given conditions for a stated time interval" (7). As discussed below, EDGs run very infrequently. Because of this, it is important to precisely define the required function and time intervals we are considering when specifying reliability metrics.

Reliability is the probability that the component will perform its function for time *t* and is designated R(*t*). Equivalently it is the probability that the component will have no failures between the time at which it is required to operate (*t=0*) and time *t* in the future. The failure probability is the cumulative distribution function for failures from *t=0* to time *t* and is given by:

$$F(t) = 1 - R(t)$$

If we take the first derivative of a cumulative failure distribution function, we obtain the failure probability density function:

$$f(t) = dF(t)/dt$$

A common metric used to describe nonrepairable components is the mean time to failure (MTTF).

$$MTTF = \int_0^\infty t \times f(t)\, dt = \int_0^\infty R(t)\, dt$$

Although EDGs are repairable, we use MTTF to define the failure rate as a function of run time. Upon repair, an EDG may again be started, but that constitutes a new run time interval. Typically, the mean time between failure (MTBF) is used to define the reliability of repairable components. But because EDGs sit idle most of their lifetimes, MTBF cannot be used to estimate the probability of an EDG's runtime failure. We will return to this distinction in the next section.

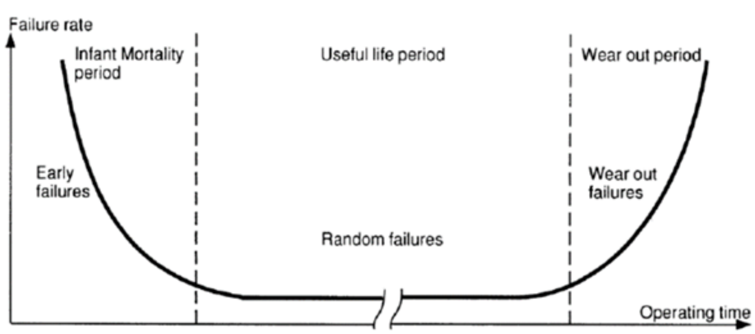


Figure 3. Reliability bathtub model showing a near cnstanr failure rate in the useful life period.

In this study, we assume that the generator has passed acceptance testing, was properly engineered and manufactured, and is not near the end of its life when it should be replaced. In terms of the reliability literature's "Bathtub Model" (Figure 3), the generator is in its useful life period. During this period, we assume that the failure rate while running, λ, is constant. If one considers only run time failures, R(t) is:

$$R(t) = e^{-\lambda t}$$

Where:

$$\lambda = 1/MTTF$$

3.2 Emergency Generator Reliability Metrics

Most energy reliability assessments are concerned with systems or components intended to operate continuously. EDGs run very infrequently and sit in a cold state for most of their lifetimes. The Clean Air Act regulations limit their operations to 200 hours a year for nonemergency use, but most run less than that.

The standard source for reliability data for equipment used in industrial and commercial power systems is the Institute of Electrical and Electronics Engineers (IEEE's) Gold Book (8), recently updated in IEEE's 3006.8 Recommended Practice for Analyzing Reliability Data for Equipment Used in Industrial and Commercial Power Systems (9). IEEE provides summary data on key reliability metrics for hundreds of components. The summary data is based on data from two major collection efforts conducted by the U.S. Army Corps of Engineers Power Reliability Enhancement Program (PREP). [redacted]

[redacted]

- [redacted]
- [redacted]

[redacted]

To properly account for the intermittent use of EDGs, we define an MTTF in terms of the rate of failures while the EDG is running, assuming the EDG has successfully started and carried the load. This can empirically be calculated as:

$$MTTF = \frac{total\ run\ time}{number\ of\ failures\ while\ running}$$

This metric is independent of the grid's reliability and the EDG's testing frequency and is dependent only on the EDG cumulative run time. The impact of more frequent grid failures requiring more frequent EDG demands are factored out. We separately consider the probability that the EDG fails to start and carry the load. This can empirically be calculated as:

$$Failure\ to\ Start\ (FTS)\ Probability = \frac{\#\ failures\ to\ start}{\#\ of\ attempts\ to\ start}$$

These two metrics define the inherent reliability of an EDG (i.e., independent of the grid's reliability and the testing frequency of the unit). Since EDGs are repairable, one often encounters the metric MTBF (8) (9) (10), defined as:

$$MTBF = \frac{lifetime}{number\ of\ failures}$$

which is independent of whether the failure occurred upon start or while running and is dependent on the frequency of demands on the EDG due to testing and grid outages. The MTBF is simply the inverse of the annual failure rate. MTBF or equivalently annual failure rates are provided in the IEEE literature and should not be used when trying to estimate the run-time failure rate of EDGs during a grid outage.

One additional metric we require is the operational availability (OA) of the EDG. This is defined as the probability that the EDG is in service (or available to attempt to provide power) at the start of a grid outage.

$$OA = \frac{lifetime - \ time\ offline\ due\ repairs\ and\ maintenance}{lifetime}$$

An EDG could be offline or unavailable due to ongoing repairs initiated due to a failure or due to scheduled maintenance. These out-of-service times are characterized by the mean time to repair (MTTR), which is the mean time associated with unscheduled repairs due to failures, and the mean time to maintain (MTTM), which is the mean time associated with scheduled maintenance activities that require the system to be taken offline. OA is sensitive to maintenance and repair times, as well as the annual failure rates and maintenance schedules.

3.3 Data Sources

To our knowledge, only four data sets are both large enough[6] and relevant to EDGs to be used to estimate the required reliability metrics discussed previously. While none of these data sets provide information for all four metrics, they can be used together to provide insight on the performance of an EDG during a long-term grid outage. Below, we briefly review these four data sets (11) (12) (13) (14) and summarize their characteristics.

The data collected by the PREP that forms the basis for all reported IEEE reliability results was collected from over 200 sites in the United States and Canada. The sites include military facilities, hospitals, and universities. PREP collects data by surveys from facilities and follows up with site visits when possible. The PREP data for EDGs is divided into two size classes: <250 kW and 250 kW-1,500 kW. The PREP data does not include information on the number of attempted starts or run time of the EDGs. Thus, estimates for FTS and MTTF based on run time cannot be constructed. PREP data includes the number of failures as a function of the observation time or, equivalently, the annual failure or MTBF. PREP data also includes detailed data on the time required for maintenance activities and the time to repair in case of failures which can be used to estimate availability. While this data set does not provide metrics for FTS or MTTF, it will be used later in this study to estimate maintenance and repair time to calculate OA.

Maintenance frequency and practices affect an EDG's availability and reliability. PREP rates each site according to the quality of maintenance employed and categorizes the sites into three tiers:

- *Above average maintenance* is reserved for facilities that followed a scheduled preventative maintenance policy equivalent to the manufacturer's suggested policy; meets National Fire Protection Association (15) or DoD's Unified Facility Criteria (16) recommended maintenance practices; uses specialized equipment tests (thermograph, vibration analysis, oil analysis); and has complete spare parts kits for the equipment. 25% of the PREP sites employ above average maintenance.
- *Average maintenance* also rigorously follows recommended maintenance schedules but does not use specialized equipment or have complete spare parts on hand. 57% of PREP sites employ average maintenance practices.
- *Below average maintenance* either has no formal maintenance policy and schedule or fails to follow one. 17% of PREP sites employ below average maintenance.

For the purpose of this study, we partition maintenance practices into two classes: well-maintained EDGs, which include both average and above average maintenance practices; and poorly maintained EDGs, which are equivalent to below average maintenance. An EDG on a military base that rigorously follows Unified Facility Criteria guidance is well-maintained.

A study conducted in Hong Kong (11) reported data on 147 EDGs monitored for an average of five years. The data was collected via a generator reliability survey followed by site visits when feasible. The EDGs were used in commercial, residential, industrial, and institutional settings to provide backup power during a grid failure. They ranged in size from 80 kW to 1,500 kW, which is typical of EDGs used on military bases. The distribution of the sizes was not reported. The

[6] Given the low probability of failure, a data set must be large enough to yield a result in which the confidence intervals for the key metrics are not meaningless.

authors reported that poor maintenance practices resulted in high reported FTS of 1.65% and an MTTF of only 61 hours. This data set provides a benchmark for EDGs in the below average or poorly maintained category. Obviously, there is a wide range of maintenance practices that are classified as poor. Thus, this case should be viewed as only one example.

In the United States, the Nuclear Regulatory Commission (NRC) requires that the performance data on EDGs that support nuclear power plants be reported routinely. Like all EDGs, those at nuclear power plants do not operate all the time. They are required to operate when the grid power is down and during shutdown periods. The demands and run hours are reported on a quarterly or semi-annual basis, and existing regulations established the requirements for testing of these on-site power sources. Therefore, an extensive database on these EDGs exists. Recent analysis of this database (13) has calculated the EDGs' reliability metrics. All demand types on the EDGS are considered, including both testing, as well as operational. These EDGs range in size from 50 kW to 499,999 kW, and most are considerably larger than those used on military bases. The sizes of the EDGs in this database are summarized in Figure 4.

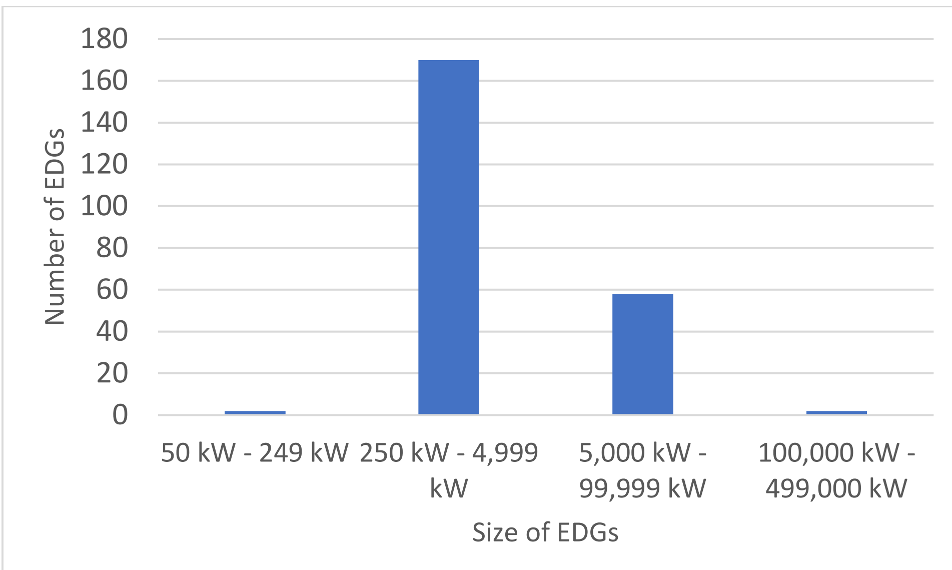


Figure 4. EDG size distribution in NRC database

Since this data set represents all EDGs used at U.S. nuclear power plants, it provides insight into an industry that requires high reliability, and the EDGs are assumed to be well-maintained. They reported an FTS of 0.66% and a MTTF of 636 hours, considerably better than the results for the smaller poorly maintained EDGs in the Hong Kong study. Due to the EDG size distribution of this data set, direct comparison of their reliability performance for military applications cannot be done. We include them in this study to provide an example of reliability for another industry (i.e., nuclear power).

The final data set we consider was collected in support of a Ph.D. thesis (14) supported by the U.S. Navy. The research was intended to provide facility managers with data to optimize the staffing level and generator maintenance. The scope of the study was limited to modern, high-efficiency, low-emission generator sets. Maintenance logs that followed current government regulations were collected and entered into a structured database. The sample population included EDGs between 10 kW and 2,000 kW. Figure 5 shows the EDG size distribution for this database.

The database contains information on run times, as well as attempted starts and failures. Detailed information on the maintenance practices were recorded but do not include data on downtime due to maintenance time or repair time due to failures. This data set will be used to provide a benchmark for EDGs used on military installations that are well-maintained. Metrics calculated from this dataset are reported and discussed in the following section.

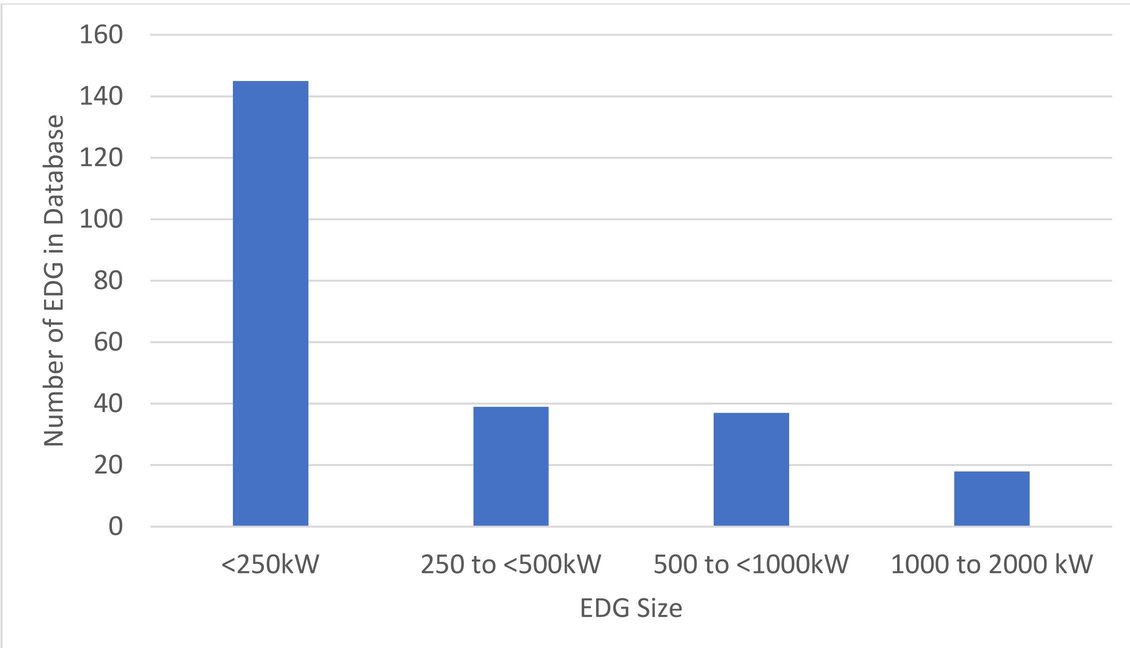


Figure 5. EDG size distribution in the Fehr database

The characteristics for these four data sets are summarized in Table 2.

Table 2. Summary of EDG Data Set Characteristics

Source	# EDGs	EDG Years of Observation	Available or Derivable Metrics	Comments
PREP	304	2,298	• MTBF • MTTR • MTTM • OA	• Representative size EDG (≤1,500 kW) • Mixed maintenance
Hong Kong	147	790	• MTTF • MTBF • FTS	• Representative size EDGS (80 kW-1,500 kW) • Poorly maintained
NRC	232	1,790	• MTTF • MTBF • FTS	• Large EDGS (most > 1 MW) • Well-maintained
Fehr	239	1,281	• MTTF • MTBF • FTS	• Representative size EDGS (10 kW-2,000 kW) • Well-maintained

3.4 Emergency Generator Reliability

The MTTF is the most important EDG reliability parameter when looking at EDG performance periods from days to weeks. Over long duration outages, failures while running dominate the overall reliability.

We have analyzed the recently collected Fehr data set to determine the MTTF for well-maintained EDGs. As shown in (14), this data contains no statistically significant evidence that the generator's make, model, or size (10 kW-2,000 kW) has any significant impact on reliability. Using a simple frequentist analysis,[7] the MTTF and its 90% confidence intervals are provided in Table 3. This information is compared to results from the NRC and Hong Kong data sets described above that provide information on failures as a function of run time (the PREP data does not contain information on run times).

Table 3. MTTF Data Including Mean and 90% Confidence Intervals for the Three Data Sets

Data Source	MTTF Low Value	MTTF Mean Value	MTTF High Value
Fehr	1,180 hours	1,662 hours	2,410 hours
NRC (13)	568 hours	636 hours	714 hours
Hong Kong	53 hours	61 hours	71 hours

The 90% confidence intervals do not overlap. The Fehr and Hong Kong data sets involve similar size and types of EDGs. The Fehr and Hong Kong data are for EDGs with significantly different levels of maintenance. The well-maintained EDGs in the Fehr data set have MTTFs over 20 times longer than seen in the poorly maintained Hong Kong data set. The NRC data set includes much larger EDGs. Whether their relative MTTF (between the other two data sets) is due to the size of the generators or the maintenance practices in the nuclear industry cannot be determined.

As stated above, EDGs are not kept on hot standby and must start and transfer power to the load when called upon during a grid outage. FTS is a rare phenomenon but significant enough to warrant its inclusion in reliability assessments. The NRC and Hong Kong data sets report number of attempted starts and failures to start. The NRC divides its failures to start into two classes: immediate failures and failures to start and carry load.[8] We include both events. For the Fehr data set, 44 FTS were observed for the 239 EDGs monitored. But the number of attempted starts was recorded only for 35 of the 239 EDGs in the data set. Three of these EDGs were installed for less than two months and were still undergoing initial testing. The average number of starts per year was 26.7, consistent with common practices. Applying this simple but crude estimate for the remaining EDGs yields 34,134 attempted starts over the observation period for the 239 EDGs, resulting in a mean FTS of 0.13%.

Table 4. Mean FTS Probabilities and the 90% Confidence Intervals

Data Source	Low Value FTS	Mean Value FTS	High Value FTS
Fehr	0.10%	0.13%	0.17%
NRC[9]	0.26%	0.66%	1.20%
Hong Kong	1.44%	1.65%	1.88%

[7] NRC (U.S. Nuclear Regulatory Commission). "About the Reliability Calculator." Last modified March 6, 2019. https://nrcoe.inl.gov/radscalc/.
[8] Failure to carry load includes any failure that occurs within one hour of starting.
[9] These are the FTS values that include both the immediate FTS and the failures to carry load.

Statistics on the FTS with 90% confidence intervals are shown in Table 4 for all three data sets (the PREP data contains no information on attempted starts). Like the MTTF metrics, well-maintained EDGs are much more reliable with the FTS probability an order of magnitude lower than for poorly maintained EDGs. The larger EDGs used in the nuclear industry have FTS and carry load roughly midway between the other two data sets. Again, the cause for this difference may be due to the size of the EDGs or maintenance practices.

The operation availability of an EDG is dependent on the annual failure rates, the time it takes to repair a failure, and the time the EDG is out of service due to scheduled maintenance activities. The PREP database contains information on the repair and maintenance times. The published mean time to repair does not include the logistics time and is not relevant for calculating an OA; however, the underlying database does include the needed information. Figure 6 shows the distribution of repair times, including logistics for all EDGs in the PREP database. Due to PREP reporting from earlier data collection efforts, PREP characterized a subset of observations by the subset's mean, which falls in the 16-24-hour interval. Thus, the data artificially appears as a bimodal distribution.

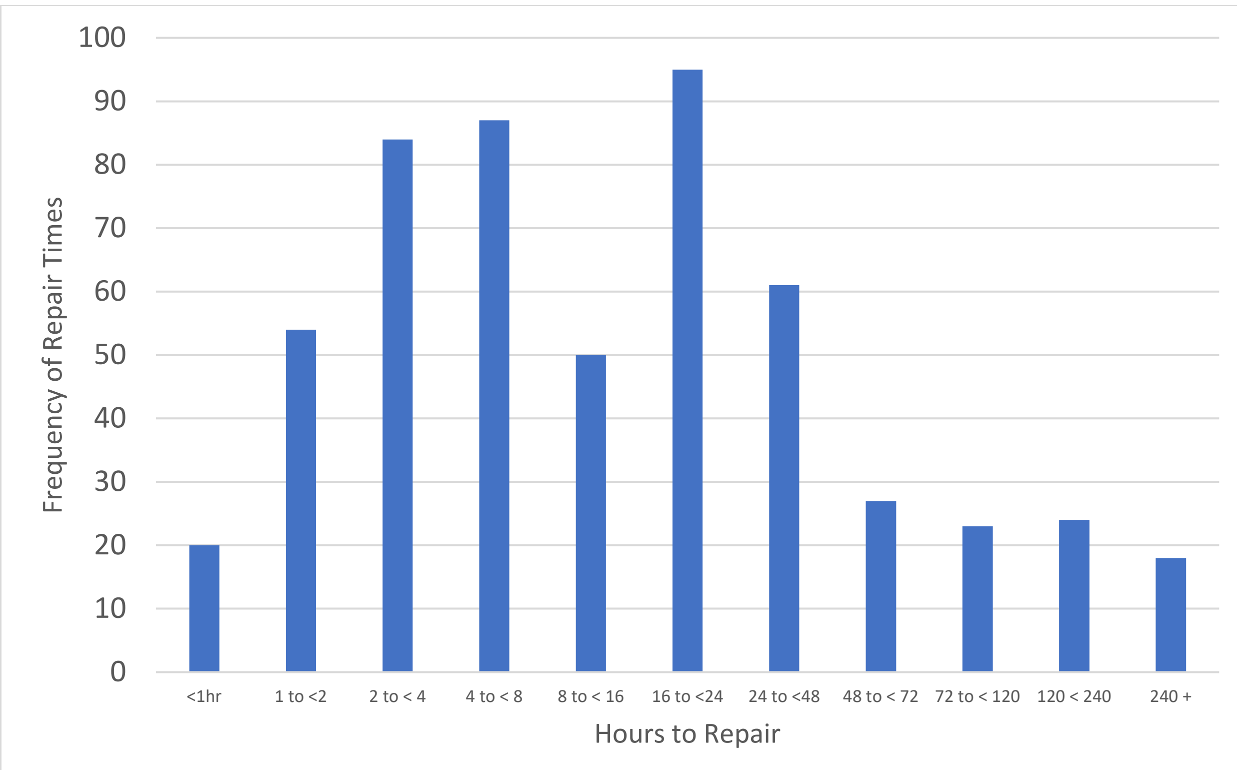


Figure 6. Distribution of repair times, including logistics for EDGs after a failure

The MTTR is 37 hours if we eliminate a single outlier, which was nearly 2,000 hours and more than twice the next-longest repair time. The MTTM is narrowly distributed, with a mean value of 1.7 hours[10]. Most outages are due to extreme weather events, and scheduled maintenance is often delayed when severe weather is expected. For assessing the performance of an EDG to provide

[10] PREP database

power during extended outages, we will ignore this short duration of an EDG being unavailable due to scheduled maintenance. Providing power for very short outages (typically less than 15 minutes) is accomplished by an uninterruptable power supply rather than an EDG, which is not the subject of this study.

Under these assumptions, the OA of an EDG or the probability an EDG can attempt to provide backup power can be calculated from annual failure rates and repair times (ignoring scheduling maintenance downtime) from:

$$OA = \frac{lifetime - time\ offline\ due\ repairs}{lifetime}$$

If we divide both the numerator and denominator by the number of failures, we find:

$$OA = \frac{MTBF - MTTR}{MTBF}$$

Table 5 shows estimates for availability for modest-sized EDGs (<2,000 kW) that are well or poorly maintained. The MTTR is taken from the PREP data and applied to the Fehr and Hong Kong data sets. The differences in OA are due to the failure rates or, equivalently, the number of required repairs.

Table 5. Availability Estimates for Different Levels of Maintenance

Maintenance	OA
Well-Maintained	99.98%
Poorly Maintained	99.84%

These high availabilities reflect the small number of runs per year of an EDG, and, thus, the small number of potential failures per year.

Combining these reliability metrics, the reliability of a single EDG at time *t* is given by:

$$R(t) = OA \times (1 - FTS) \times e^{-t/MTTF}$$

We use the estimates listed previously from the Fehr and Hong Kong data sets to model modestly sized EDGs (<2,000 kW) that are well-maintained or poorly maintained and compare these to the results for larger EDGs used in the nuclear industry. Figure 7 shows the expected reliability for a single EDG for outages that range from one hour to two weeks (336 hours).

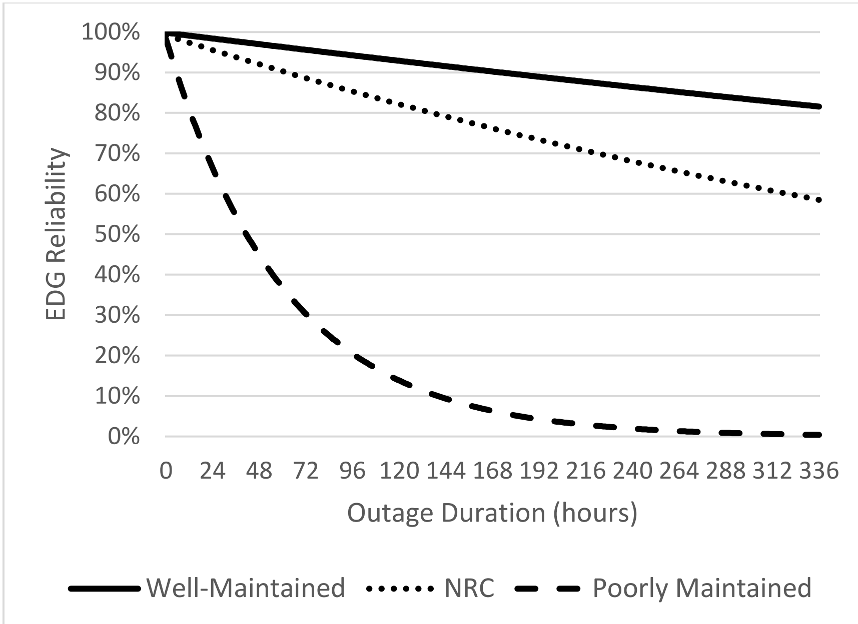


Figure 7. The reliability of a single EDG over two weeks (336 hours)

In Figure 8, the same reliability results for outages up to 12 hours are shown to clearly illustrate the impact of different probabilities for FTS.

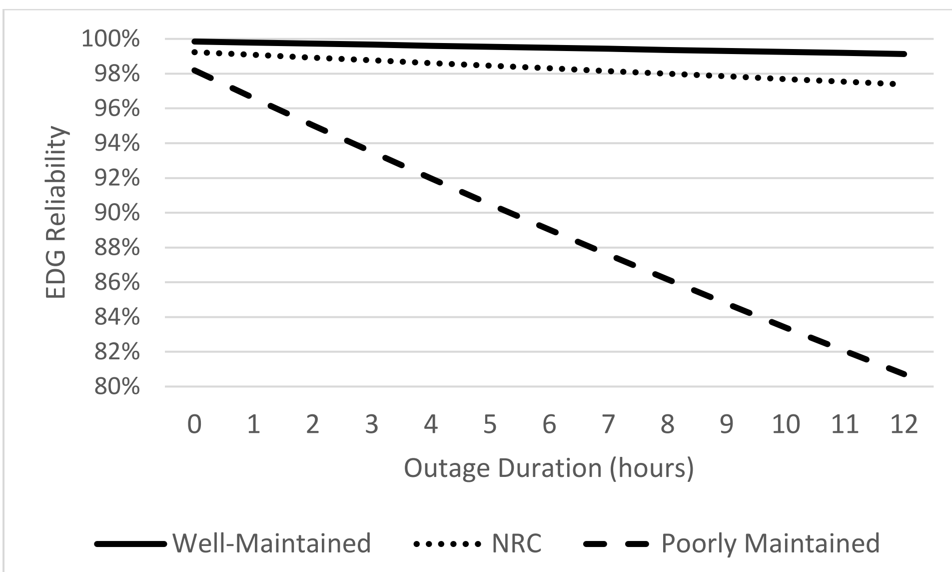


Figure 8. The reliability of a single EDG for outages less than half a day (12 hours)

Figure 9 shows the reliability range expected for a well-maintained EDG with its 90% confidence intervals.

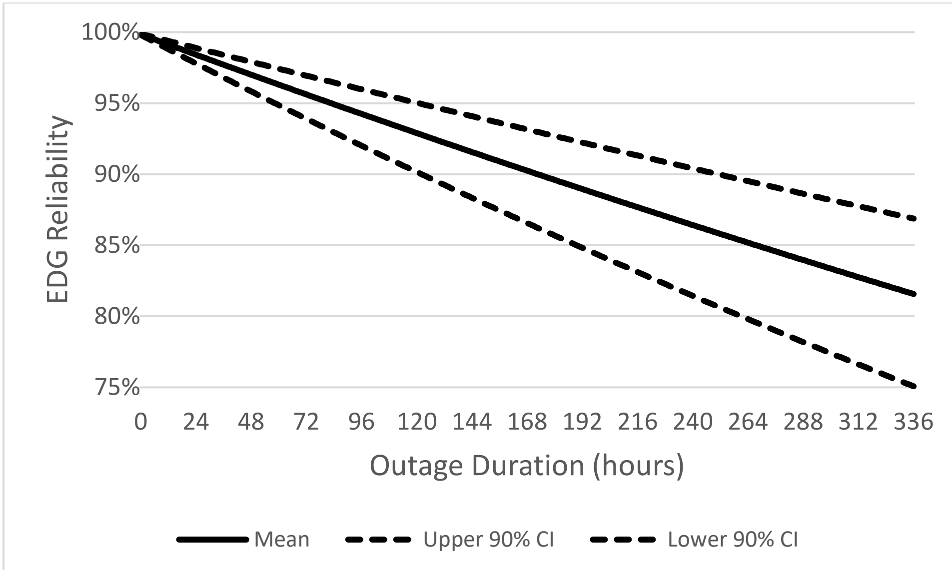


Figure 9. Mean and 90% confidence interval reliabilities for a well-maintained EDG for outages up to two weeks (336 hours)

Not surprisingly, a poorly maintained EDG is unlikely to provide power for durations longer than a few days, and it has reliabilities of only 80% at 12 hours. These figures reinforce the importance of following the current guidance on EDG maintenance. But even well-maintained EDGs have a reliability of 92%-96% for providing backup power for four days (96 hours), 90%-95% at one week, and 75%-87% at two weeks (required for critical loads at some military facilities). Thus, a single EDGs reliability limits their ability to provide a robust source of emergency power for critical loads over multiday outages.

4 System Reliability

Building-tied EDGs and microgrids require different approaches for assessing reliability. Building-tied EDGs can be assessed using a simple fault tree approach, while networked EDGs require a more sophisticated analysis. Although the primary purpose of a microgrid is to provide power to the critical loads during a grid outage (17) (18), almost all the existing analysis and modeling tools to design and assess microgrid performance do not calculate a microgrid's reliability due to the nonperfect reliability of the DERs that power the system (19). The rare examples of microgrid reliability assessment in the literature are conceptual (20) or use complex Monte Carlo simulations (21). None of them factor in the realistic reliabilities of EDGs that drive the reliability performance of currently deployed microgrids. Below we first describe a simple fault tree analysis sufficient for estimating the reliability of a system composed of stand-alone EDGs and next describe an approach that allows one to estimate the reliability of a microgrid based on EDGs. In both cases, we assume that if an EDG fails at the start or during and outage it is not repaired during the outage. The MTTR of an EDG is 37 hours for all failures (see Figure 6). In the case of a long duration grid outage, we expect the ability to respond to an EDG failure will be worse. Thus, it is unlikely during these extreme events parts and staff will be readily available to diagnose the failure and repair the EDG.

4.1 Building-Tied

We consider building-tied systems with one and two generators per building. In the first case, the building loses power when the generator fails while in the second case the building loses power only when both generators fail. Military installations often used a combination of these configurations. Most buildings have one EDG providing backup power and subset of buildings with the highest priority critical load will have two EDGs. We will return to this issue and illustrate its impact in Section 5, but in this section treat them as two separate systems to show the range of building-tied system performance. Providing two EDGs for every building requiring power during a grid outage would be prohibitively expensive.

A generator can fail due to being unavailable at the start of an outage, being available but failing to start, and starting but subsequently failing to run. The reliability that a single generator tied to a building survives an outage of duration d, $R_1(d)$, is given by the reliability for the generator as a component:

$$R_1(d) = OA \times (1 - FTS) \times e^{-d/MTTF}$$

If two generators are connected to a building, then the system survives if at least one of the generators survives. The survival probability is then calculated by determining the likelihood that the first or second generator survives, which is given by:

$$R_2(d) = 2 * R_1(d) - R_1(d) * R_1(d)$$

The situation is slightly more complicated if one considers a military installation where critical loads occur in multiple buildings. If we consider b buildings with critical loads, the probability every building has power during an outage, $PAB_i(d)$, is:

$$PAB_i(d) = R_i(d)^b$$

because each building is independent. Where the subscript *i* indicates if it is one or two EDGs tied to each building.

An alternative way to view these results is to calculate the number of buildings that have power during an outage. Assume we have *b* buildings with critical loads on the base each with a survivability $R_i(d)$. The probability, $\mathcal{P}(k,b)$, that *k* buildings, have power during an outage at time *d* is given by the binomial distribution:

$$\mathcal{P}_i(b,k,d) = \binom{b}{k} {R_i}^k (1 - R_i)^{b-k}$$

The mean fraction of buildings with power is equal to the mean value of the binomial distribution divided by the total number of buildings and the mean fraction of buildings without power or the expected power lost in terms of fraction of buildings is:

$$EPLB_i(d) = 1 - R_i(d)$$

which is independent of the number of buildings.

4.2 Microgrid

Calculating the reliability of a microgrid system is more involved than calculating the reliability of a single building-tied EDG. Building-tied generators are sized to meet the peak building load, and the system reliability does not depend on the underlying load profile. The EDGs that power a microgrid can supply power to any building on the microgrid network. Thus, the amount of redundancy at each hour depends on the critical load at that hour. Critical loads vary with season, day of week, and time of day. Consider a large military base with an annual peak hourly critical load of 10 MW. A microgrid system powered by a set of 750 kW centralized EDGs would require at least 14 EDGs to meet that peak load. Typically, a microgrid would be designed to have an N+1 configuration (15 EDGs) to meet the peak critical load and provide some redundancy. Figure 10 displays the critical load profile for this military base in terms of kWhr and units of EDG capacity.

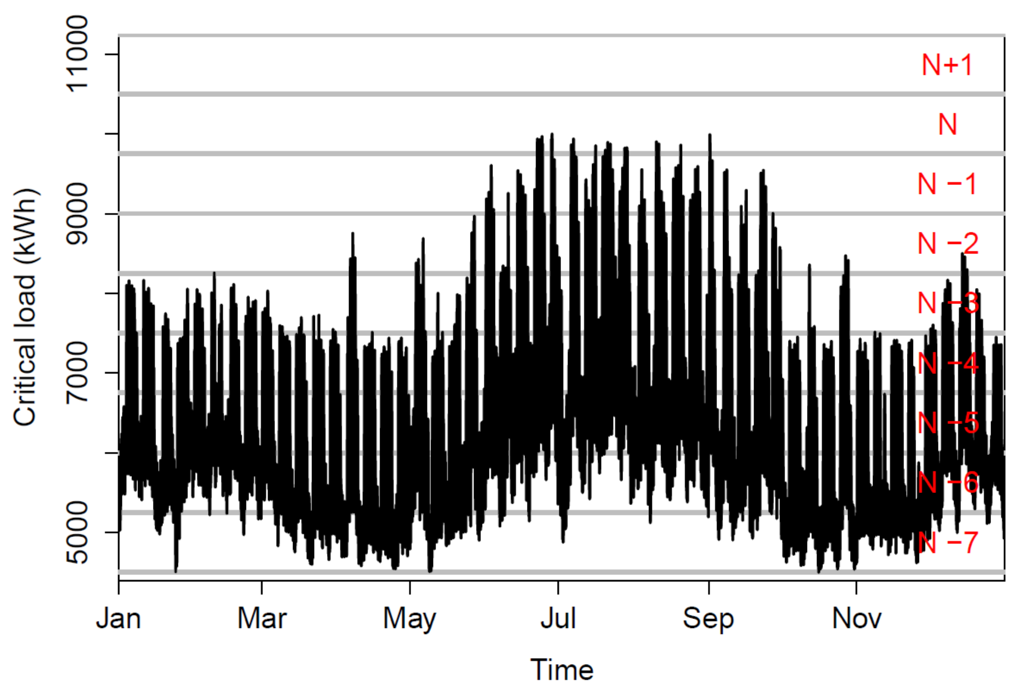


Figure 10. Critical load profile for large base in units of kWh and EDG redundancy

During most times of the year, multiple EDGs would need to fail for the microgrid system to be unable to meet the load requirement.

Figure 11 shows the distribution of load for this large base over a year ordered by size. The microgrid system for this large base has N+1 reliability for the peak load but has N+5 or more redundancy for more than 80% of the year. This illustrates why microgrids are an inherently more reliable system than building-tied systems.

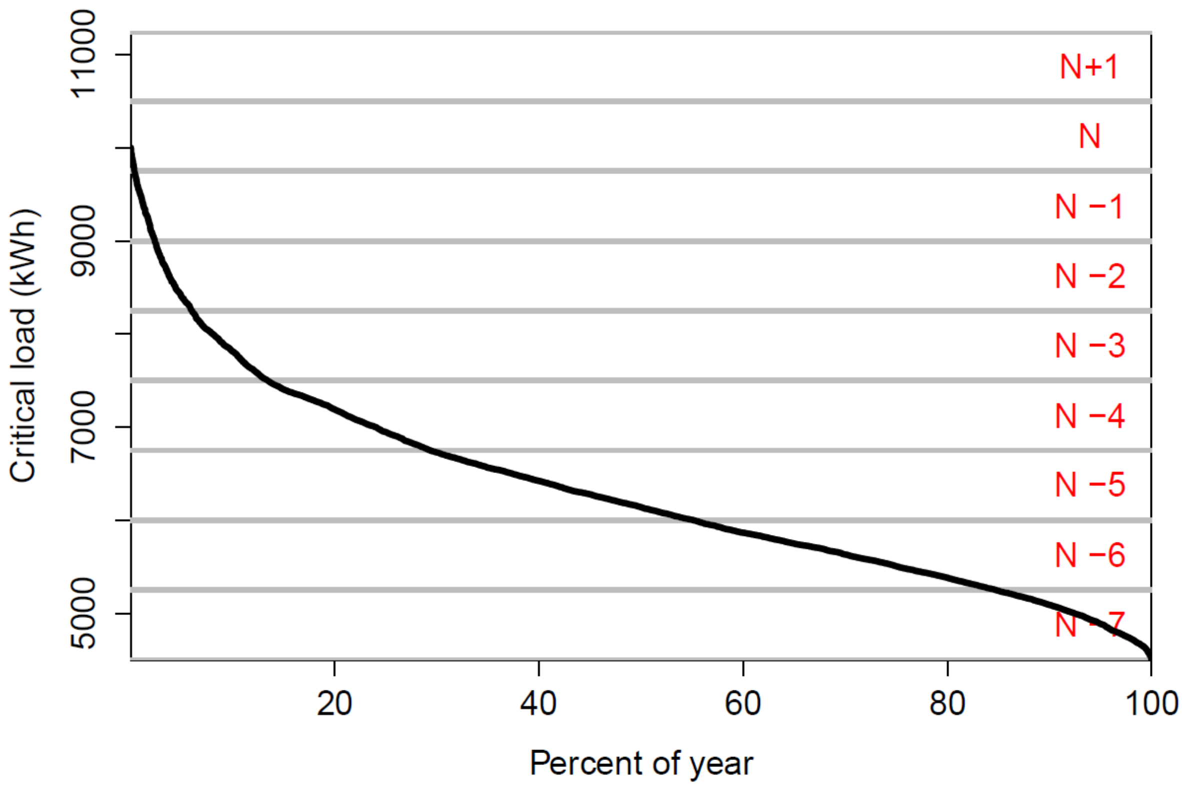


Figure 11. Critical load for large base ordered by load size

To determine the likelihood of survival and the expected critical load shed, we take into account the variability of critical load across the year. Because we model the likelihood of survival hour to hour, we use a discrete representation of component reliability for the microgrid analysis in place of the continuous formulation used for individual buildings. Given a microgrid with N generators, the probability that n generators will be available, and start in hour zero of the outage is given by $P(0,n)$:

$$P(0,n) = \binom{N}{n} \left(OA * (1 - FTS)\right)^n * \left(1 - OA * (1 - FTS)\right)^{N-n}$$

Which is simply the combinatorics formula for n generators being available and not failing to start, and $N - n$ generators being unavailable or failing to start. We assume all EDGs try to start at the beginning of the grid outage. Although all might not be required, EDGs are ideally run at less than 100% capacity. Typical guidance recommends the optimal load for a generator should be in the range of 50% to 80%. The average hourly critical load for our cases is on the order of 50 to 60% and peak load is between 80% and 90% if all EDG are running. Starting all EDGs at the beginning of a grid outage and allowing them to continue to run ensures the EDGs are properly loaded. Given n generators are currently running, the probability that n' generators are running in the next hour is given by $p(n, n')$:

$$p(n, n') = \binom{n}{n'}(1 - FTR)^{n'} * FTR^{n-n'}$$

where FTR is the discrete hourly version of exponential decay rate. The probability of n generators still operating after d outage hours, denoted $P(n, d)$, can be found using a Markov matrix, as follows:

$$\begin{bmatrix} P(0,d) \\ P(1,d) \\ \vdots \\ P(N,d) \end{bmatrix} = \begin{bmatrix} 1 & p(n,0) & \cdots & p(N,0) \\ 0 & p(n,n') & \cdots & p(N,n') \\ \vdots & \vdots & \ddots & \vdots \\ 0 & \cdots & 0 & p(N,N) \end{bmatrix}^d \begin{bmatrix} P(0,0) \\ P(1,0) \\ \vdots \\ P(N,0) \end{bmatrix}$$

The amount of curtailed load in a given hour depends on both the critical load and the total capacity of generators operating in that hour. The curtailed load for an outage starting at time t, in outage hour d, given n currently working generators, each with a capacity of k, is given by:

$$C(n, d, t) = max\ (0, L(t + d) - k * n)$$

Where $L(t + d)$ denotes the critical load in hour $t + d$ and C denotes the amount of load curtailed. Assuming outages occur throughout the year with equal frequency, then the microgrid's expected percent of load shed for an outage of duration d is:

$$EPLS_m(d) = \left(\frac{1}{L(t + d) * 8760}\right) \sum_{t=1}^{8760} \sum_{n=0}^{N} P(n, d) * C(n, d, t)$$

The above equation says that the expected load shed in outage hour d is the sum of curtailed load across the possible number of working generators weighted by the probability that that number of generators is working in outage hour d. It is the microgrid equivalent for fraction of buildings without power, $EPLB_i(d) = 1 - R_i(d)$, in the case of building-tied systems.

To calculate the probability that all buildings have power, we need to determine the likelihood that no load is curtailed for the entirety of the outage. The procedure for this calculation is very similar to the one described above, but we remove outages in each hour that do not have sufficient capacity to meet load. The probability of survival, which for the microgrid is denoted $S_m(n, d, t)$, is determined iteratively by the following two steps:

$$\begin{bmatrix} S'(0,d,t) \\ S'(1,d,t) \\ \vdots \\ S'(N,d,t) \end{bmatrix} = \begin{bmatrix} 1 & p(n,0) & \cdots & p(N,0) \\ 0 & p(n,n') & \cdots & p(N,n') \\ \vdots & \vdots & \ddots & \vdots \\ 0 & \cdots & 0 & p(N,N) \end{bmatrix} \begin{bmatrix} S_m(0,d-1,t) \\ S_m(1,d-1,t) \\ \vdots \\ S_m(N,d-1,t) \end{bmatrix}$$

$$S_m(n, d, t) = \begin{cases} 0 & C(n, d, t) > 0 \\ S'(n, d, t) & C(n, d, t) = 0 \end{cases}$$

Where the initial survival conditions $S_m(n,d,t) = P(n,0)$. In other words, for each hour we determine the likelihoods of having n working generators and then set the probability of survival to zero for systems that have insufficient generation capacity to meet critical load. The probability that all the critical loads are supported by the microgrid, $PAL_m(d)$, for an outage of duration d is then calculated as:

$$PAL_m(d) = \left(\frac{1}{8760}\right) \sum_{t=1}^{8760} \sum_{n=0}^{N} S_m(m,d,t)$$

This is the microgrid equivalent for load of the building-tied system probability for buildings given by $PAB_i(d) = R_i(d)^b$.

5 Model Installations

DoD manages real property in all 50 states, 8 U.S. territories, and 45 foreign countries.[11] This includes over 270,000 buildings on hundreds of installations worldwide. Military installations vary in size and energy demand. They range from small bases that have only a few hundred thousand square feet of building space to extremely large installations with over 20 million square feet. There is no one case that represents a "typical" base. We restrict our attention to military installations with more than 1 million square feet of building space, which constitute over 96% of DoD's building footprint worldwide. To provide information that is relevant to the most bases we have created a series of model installations that span common conditions.

5.1 DoD Installations' Energy Consumption

The primary metric that characterizes an installation's backup power demand is its peak critical load. This establishes the size of generation needed for a microgrid and is roughly proportional to the number of buildings that have critical loads. On average, electricity accounts for 51% of all military installation energy consumption (3). The fraction of that electric load that is critical can vary from less than 10% to over 50%. Based on reviews of dozens of installations, critical load is typically 30% of total load and hourly peak load is commonly 170% of the annual average load.

We can estimate the range of critical hourly peak load found across DoD installations based on data in DoD's Annual Energy Management and Resilience Report (3). Figure 12 shows a histogram of the number of installations as a function of the hourly peak critical load under the assumptions described above.

[11] Base Structure Report – Fiscal Year 2018 Baseline https://www.acq.osd.mil/eie/Downloads/BSI/Base%20Structure%20Report%20FY18.pdf.

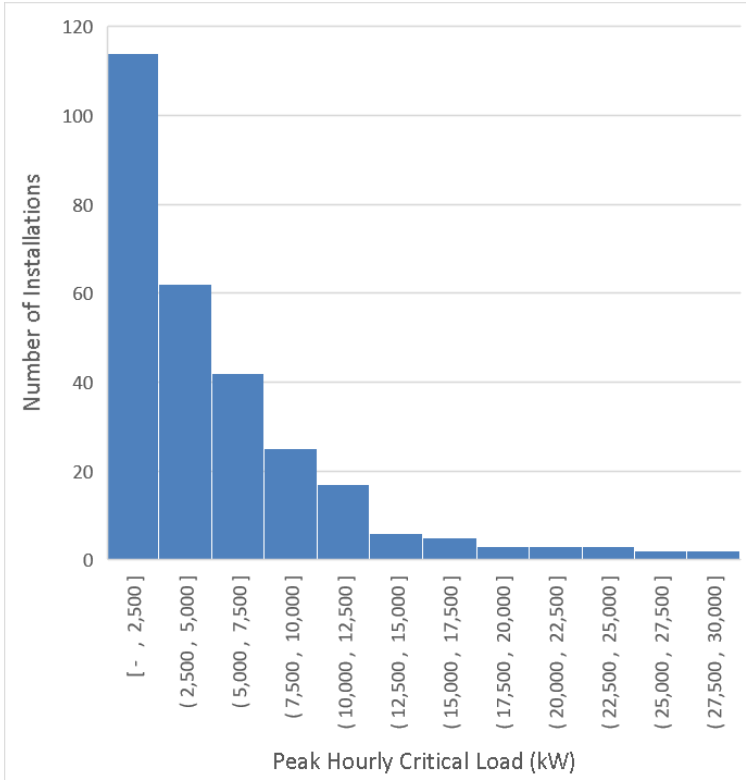


Figure 12. Peak hourly critical load for all DoD installation with buildings with more than 1 million square feet of floorspace

To sample this variation of critical peak load, we have modeled four installation with peak critical electric loads ranging from1 MW to 20 MW.

5.2 Installation Case Studies

For each installation, we model three potential energy assurance architectures based on EDGs. The first is a system where a single EDG is tied to each building with a critical load. The second is where two EDGs are tied to each building with a high priority critical load. Most military bases use a combination of these two approaches, where most buildings with critical load are supported by a single EDG and subset of buildings with high priority critical loads are supported by two EDGs. We assume that buildings with critical loads have roughly equal energy loads on the order of 100 kW. The number of buildings requiring backup power ranges from 8 for the small base to 160 for the very large base.

The third energy assurance architecture is a microgrid powered by centralized EDGs. We design the microgrid with N+1 EDGs, where N is the number of EDGs to meet the peak critical load and one additional EDG for higher reliability. To assess the performance of a microgrid system requires knowing the critical load profile. This is important because a network (i.e., a microgrid) of EDGs can support any building with a critical load, and, thus, the effective redundancy of EDGs as shown above varies over time depending on the load profile. For building tied EDGs this information is irrelevant as each EDG cannot support any other building even if it has excess capacity. Hourly load profiles from multiple military installations were gathered and reviewed. Based on similar size bases, typical load profiles were created for each size base being modeled.

The size of the microgrid EDGs for each modeled base was chosen in accordance with common engineering trade-offs. EDG sizes were constrained to 250 kW, 750 kW, and 2,000 kW. Figure 15 shows the annual critical load profiles with the generator step sizes used in this study. Using the smallest size EDG will lead to the largest number of EDGs and therefore the highest O&M maintenance costs. Using larger EDGs can limit the ability to expand cost effectively to meet future load growth and maintain a common fleet of EDGs.

Based on these considerations, the number of buildings, and the size and number of EDGs for the microgrid configurations for each base are listed in Table 6.

Table 6. Annual Hourly Peak Critical Load, Number of Critical Buildings, and N Generators for the Microgrid Scenario for the Small, Medium, Large, and Very Large Bases Sizes Modeled

Base	Small	Medium	Large	Very Large
Peak Critical Load (MW)	1	5	10	20
Mean Critical Load (MW)	0.6	2.8	6.3	11.2
# Buildings With Critical Loads	8	40	80	160
Microgrid EDG Size (kW)	250	750	750	2000
Number of Microgrid EDGs	5	8	15	11

The hourly load profiles in units of kW and EDG capacity is shown in Figure 13.

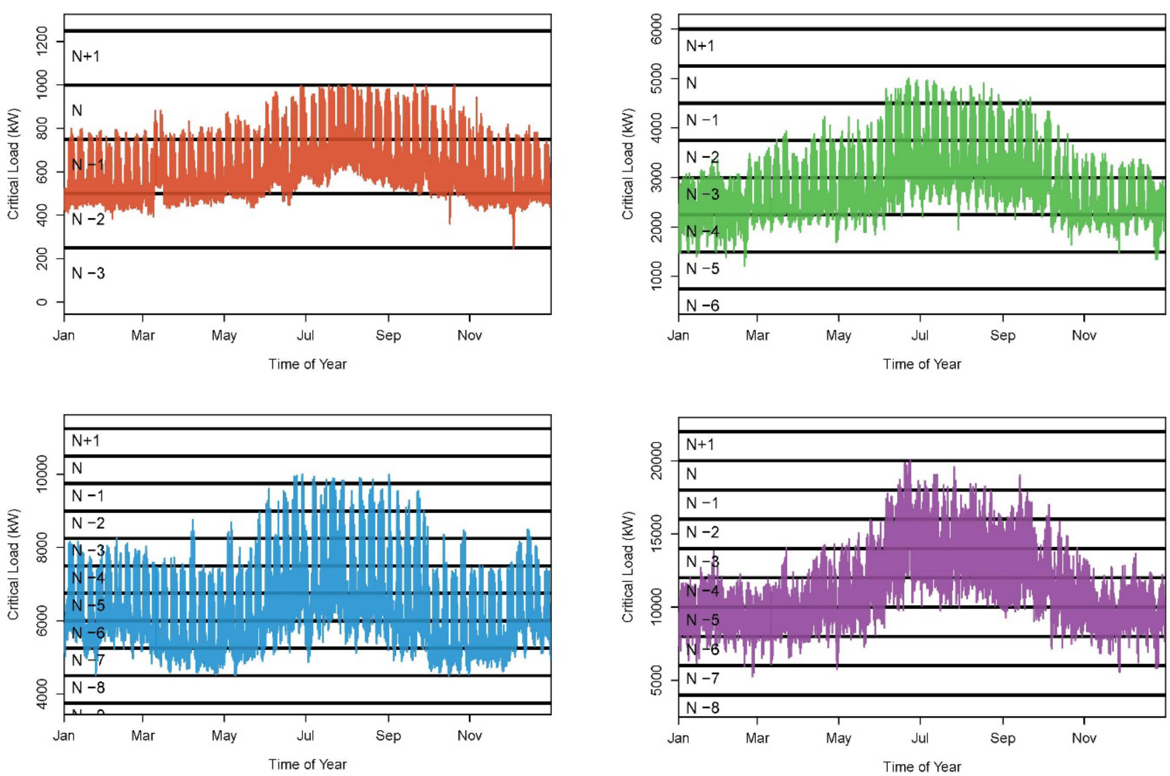


Figure 13. Modeled base critical load profiles with generator step sizes for small (top left), medium (top right), large (bottom left), and very large (bottom right) bases

6 Installation Results

Three reliability system performance metrics are illustrated below for well-maintained EDGs. Poorly maintained generators do not meet the needs of military installations independent of how they are arranged. Even in a microgrid configuration, the loss of multiple generators within a few days due to poor maintenance yields inadequate performance.

First, we show the probability that all critical load will be 100% supported as function of outage duration for a microgrid versus one EDG tied to each building. This is the most sensitive metric in that any loss of load is considered a failure. Next, we show the mean fraction of lost load for a microgrid and the mean fraction of buildings without power for a single EDG per building tied systems. In the microgrid case, the loss of load can be managed by shedding lower priority critical loads to maintain microgrid stability. In the case of building-tied systems, there is no action that can compensate for the EDG's failure. Finally, we look at the impact on the highest priority critical loads, typically only a fraction of the total critical load. These are loads that support high priority critical missions, which must be sustained. For this case we will compare a microgrid to a system of two EDGs per building.

Probability to Support 100% of Critical Load: Figure 14 shows the probability of meeting 100% of the critical load for an N+1 microgrid and a single EDG tied to each building for the four model bases using the mean estimates for a well-maintained individual EDG's reliability. This is a stringent metric and it shows the large difference between a microgrid reliability due to EDG failures and single building-tied EDGs. The larger the base, the more building-tied generators are required, which increases the likelihood that one or more generators will fail.

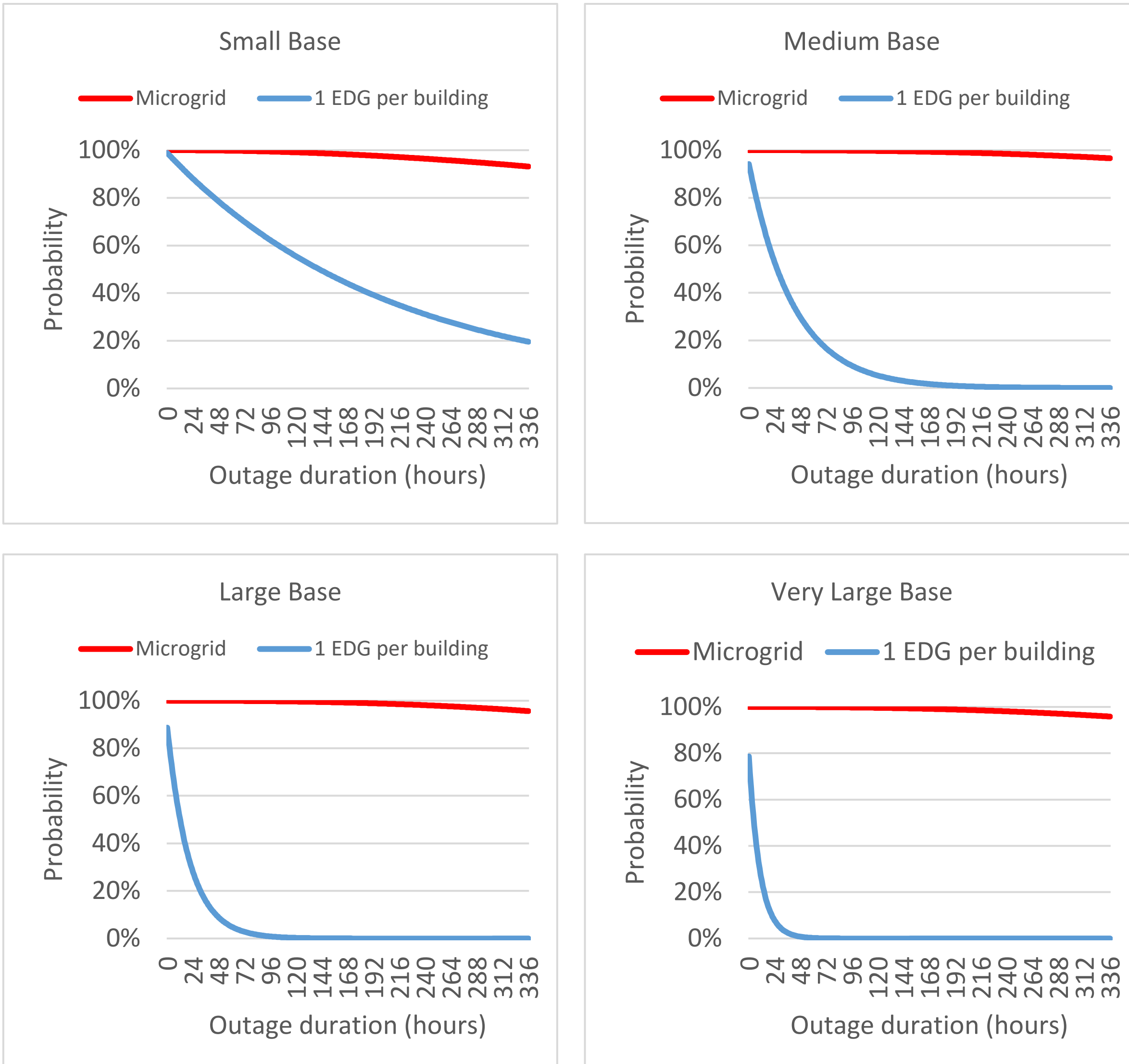


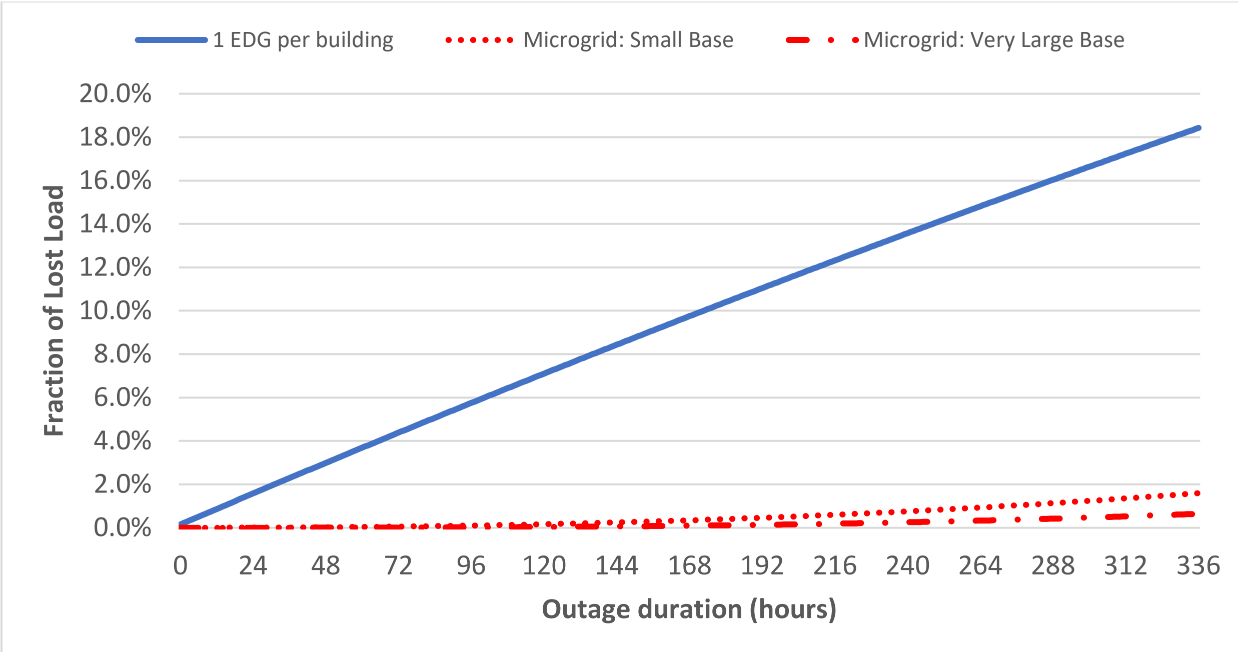
Figure 14. The probability of meeting 100% of the critical load requirement for outages up to 14 days (336 hours). Small (top left), medium (top right), large (bottom left), and very large (bottom right) bases

Table 7 shows the 90% confidence range for the performance of the N+1 microgrid configuration and the single stand-alone EDG per building for outages of 1, 3, 7, and 14 days. The confidence range is based on the 90% confidence intervals for an EDG's reliability data shown in Table 4. The ranges show the uncertainty in the results is much smaller than the large difference between the two architectures. In addition, although the number of EDGs determines the performance of the stand-alone systems, microgrid performance is impacted by both the number of centralized EDGs and the characteristics of the load curve.

Table 7. 90% Confidence Ranges for the Probability of Meeting 100% of the Critical Load for a Microgrid and a Single Stand-Alone Building-Tied EDG at 1, 3, 7, and 14 days

Base	Very Large		Large		Medium		Small	
Architecture	Microgrid (%)	Stand-Alone (%)	Microgrid (%)	Stand-Alone (%)	Microgrid (%)	Stand-Alone (%)	Microgrid (%)	Stand-Alone (%)
1 day	100	3 - 17	100	17-41	100	41 - 64	100	84 - 91
3 days	100	0 - 1	100	1-9	99 - 100	8 - 29	99 -100	60 - 78
7 days	98 - 100	0	98 - 100	0	95 - 99	0 - 6	97 - 99	32 - 57
14 days	91 - 98	0	90 - 98	0	85 - 97	0	87 - 97	10 - 32

Expected Lost Critical Load or Buildings: The average expected fraction of lost load for each base for a microgrid and single EDG architecture is shown in Figure 15. This figure highlights how a microgrid is expected even after a two-week outage to be able to meet nearly 100% of the critical load. The small loss of load can be compensated by the microgrid shedding lower priority critical loads. For EDGs tied to individual buildings, there is no such opportunity. By the end of a two-week outage one should expect to lose the ability to provide electric power to one or two buildings on a small base, while on a very large base, one will lose the ability to provide power to 21 to 40 buildings if single stand-alone EDGs are used.



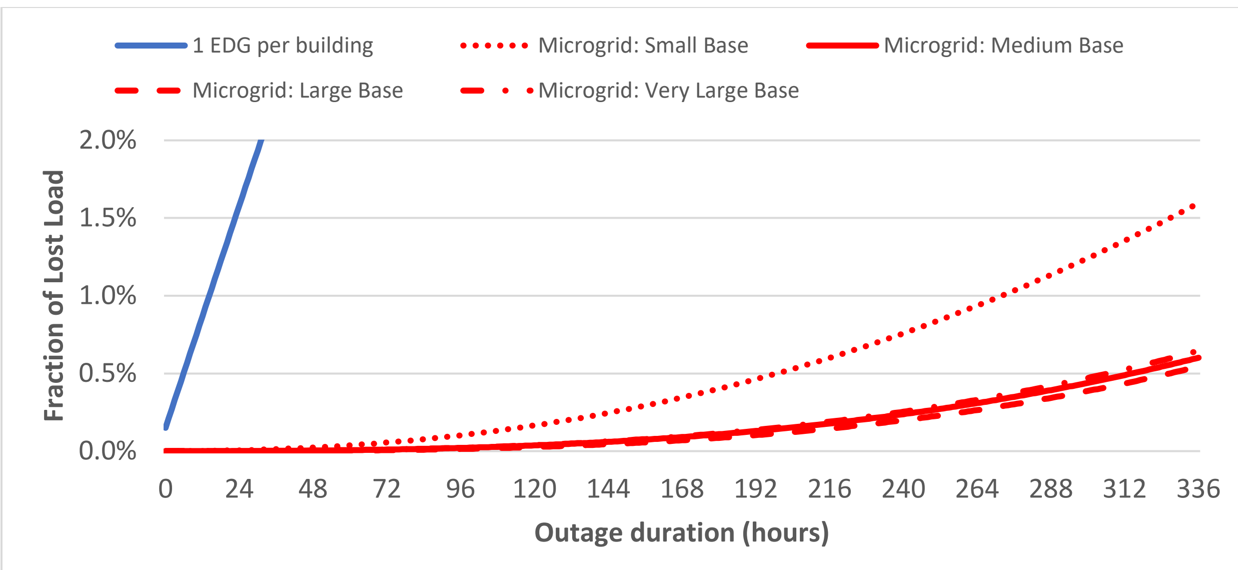


Figure 15. Mean expected lost load for a single EDG per building architecture (blue) and microgrids (red) on different size bases.

The fraction of buildings without power is the same for a stand-alone EDG system for each base. As shown in Section 4, it is independent of the number of buildings. Table 8 translates these results into the expected number of buildings without power for a stand-alone system of single EDGs tied to individual buildings and the load the must be shed for a microgrid to remain operational. Table 8 shows the 90% confidence range for the performance of the microgrid configuration and the single stand-alone EDG per building for outages of 7 and 14 days. The confidence range is again based on the 90% confidence intervals for an EDG's reliability shown in Table 8.

Table 8. 90% Confidence Ranges for the Load a Microgrid Must Shed and the Number of Buildings with Critical Load That Will Not Have Power if One Uses a Single Stand-Alone Building-Tied EDG at 7 and 14 Days

Base	Very Large		Large		Medium		Small	
Outage Duration	7 days	14 days	7 days	14 days	7 days	14 days	7 days	14 days
Stand-Alone								
Fraction of Lost Load (%)	7 - 13	13 - 25	7 - 13	13 - 25	7 - 13	13 - 25	7 - 13	13 - 25
Number of Buildings without Power	11 - 21	21 - 40	6 - 11	11 - 20	3 - 5	5 - 10	1	1 - 2
Microgrid								
Fraction of Lost Load (%)	< 0.2	0.2 - 2	< 0.2	0.2 - 2	< 0.2	0.2 - 2	< 0.7	0.7 - 3
Average kWs Not Supported	4 - 26	26 - 186	2 - 11	11 - 97	1 -7	6 - 43	1 - 5	4 -21

Probability to Meet Highest Priority Critical Loads: Perhaps the most important metric is the impact of EDG reliability on the ability to provide power to the highest priority critical loads on a base. Often, the highest priority missions require critical loads be supported across different buildings to be operational. A microgrid has an advantage in that it can prioritize loads in real time, ensuring that the highest priority loads are always satisfied. Stand-alone systems cannot change priority or shift DERs during an outage. The only way they can increase reliability for high priority critical loads is by increasing the number of EDGs linked to any individual building. Figure 16 shows the probability of meeting the highest priority load for situations where the high priority load is 10% and 25% of the total critical load for a microgrid and two stand-alone EDG per buildings.

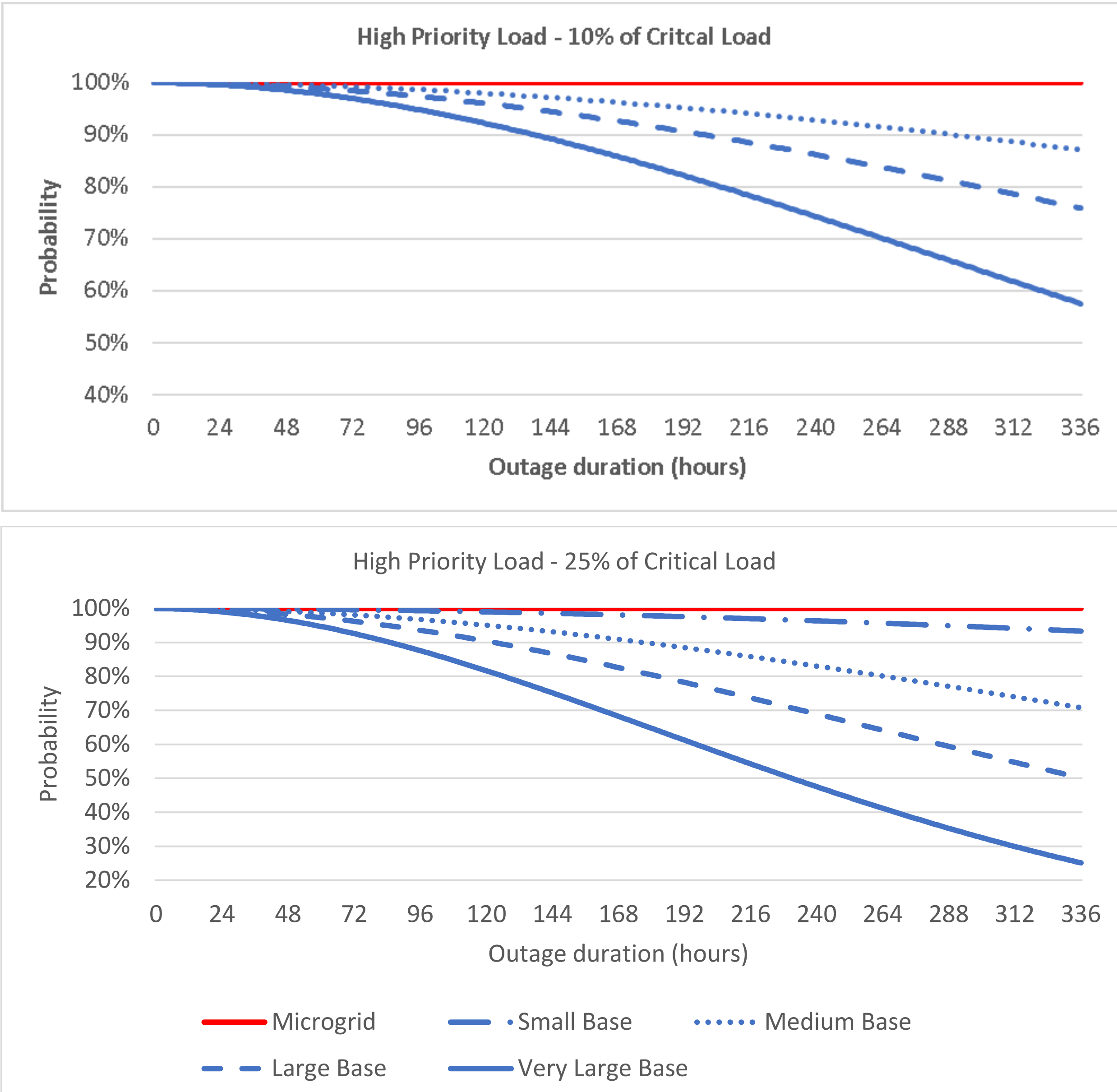


Figure 16. Probability of meeting 10% and 25% of highest priority critical load for small, medium, large, and very large bases. The red curve represents the results for all bases supported by a microgrid. The blue results are for bases where two EDGs are deployed for every building containing a high priority critical load.

For the small base no results are shown for the top 10% priority because 10% is less than one building.

Microgrids have close to a 100% probability of having power generation capacity sufficient to always meet the highest priority critical load. Stand-alone systems with two EDGs per building do not come close to meeting DoD's needs at medium, large, and very large bases. By two weeks into an outage, the probability based on mean reliability metrics drops to 25% to 71% for the top 25% priority critical load and from 58% to 87% for the top 10% priority critical load. For small bases, 25% of the critical load is contained in only two buildings. Even in this case, by two weeks into an outage the probability based on mean reliability metrics drops to 93% as comparted to near a 100% for a microgrid. Table 9 illustrates the range of probabilities that 10% and 25% of critical loads will be powered based on the 90% confidence interval for the individual EDG reliabilities.

Table 9. 90% Confidence Ranges for the Probability That the 10% and 25% Highest Priority Buildings With Critical Loads Will Have Power When Using a Stand-Alone System of Two EDGs Per Building for outage durations of 7 and 14 Days

Base	Very Large		Large		Medium		Small	
% of Critical Load	10%	25%	10%	25%	10%	25%	10%	25%
7 Days	75%-93%	48%-83%	86%-96%	69%-96%	93%-98%	83%-95%	NA	96%-99%
14 Days	36%-76%	8%-50%	60%-87%	28%-71%	77%-93%	53%-84%	NA	88%-97%

The numbers should be compared to the expected 100% available power from a microgrid for the entire 90% confidence interval for reliability metrics. We cannot assume that even a system of two EDGs per building will be able to provide sufficient power for the high priority critical loads in the event of a multiweek outage.

How many EDGs tied to each building are required to have a high confidence that the highest priority load will all have power? Figure 17 illustrates that for a large base one would require at least four EDGs per building to have a greater than 99% probability that power is available for the highest 10% of priority critical loads.

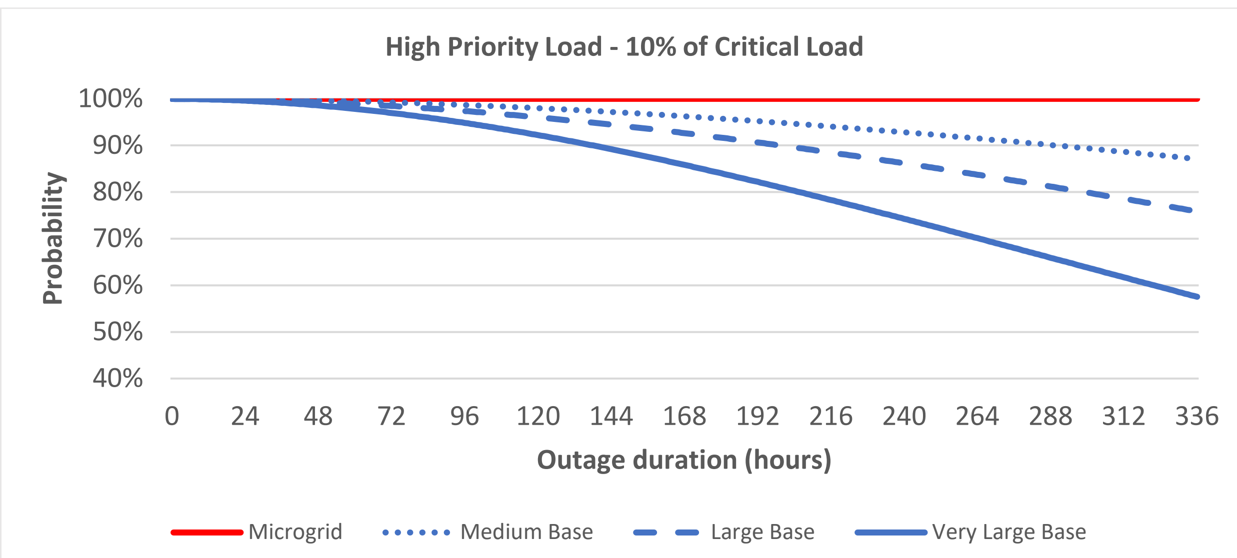


Figure 17. Probability of meeting 10% of highest priority critical load for a large base as a function of the number of stand-alone EDG per building as compared to a microgrid

All three metrics provide overwhelming evidence that stand-alone building-tied EDG systems cannot provide the level of confidence DoD needs for power to be available to support critical missions. Microgrid configurations provide a robust source of power for critical loads due to their network configuration. But microgrids do introduce other vulnerabilities that must be managed. These include cyber vulnerabilities and dependence on the on-base distribution system. Cyber vulnerabilities can be mitigated by appropriate cyber defenses. On-base distribution systems reliability varies dramatically from currently being the primary cause of outages to never being the cause. Proper maintenance and well-known mitigations can significantly reduce the likelihood of the on-base distribution system's vulnerabilities.

7 Conclusions

The current default solution for backup energy at military installations relies on EDGs. This is most often accomplished by either a single stand-alone generator or two generators tied to an individual building with critical loads. Less common, but with increasing frequency, diesel generators are networked and serve as the primary DER for a microgrid. EDGs can be unavailable due to maintenance, failure to start and carry the load, or failure to run during a grid outage. System-level reliability[12] is a key performance criterion that should be considered when assessing the relative value of different backup energy system for a specific installation. In the absence of such information, military installations cannot quantitively assess their current energy assurance vulnerabilities nor evaluate alternative approaches. This work has analyzed the impact of EDG reliability on base backup energy systems.

There has been an absence of realistic estimates for the reliability of individual emergency diesel generators. Using IEEE reported mean time between failure results in incorrect predictions. New estimates for the reliability of modern commercial emergency diesel generators that are commonly used on DoD installations based on empirical data sets are provided. Poorly maintained emergency diesel generators are unlikely to run more than a few days, and well-maintained emergency diesel generators have only an 80% likelihood of being operational at the end of a two-week outage.

For a military installation, where multiple buildings house critical loads, the impact of the reliability of a well-maintained EDG is significant. Installations that rely on a single stand-alone EDGs tied to individual buildings with critical loads are unlikely to have power for all these loads over a two-week outage. It is likely that a small base will lose power to a few buildings while larger bases will lose power to dozens of buildings. A microgrid, which is composed of a network of centralized EDGs, has a high probability that all buildings with critical loads can be supported throughout a two-week outage. The expected microgrid lost load is very small and can be managed by shedding lower priority loads. Of greatest concern is power for the highest priority critical loads. Stand-alone building-tied EDG systems manage this by placing two EDG per building (a backup to the backup). Although this improves the likelihood of having power, it does not provide the level of reliability DoD needs. Such stand-alone systems will have less than a 50% probability of supporting the highest priority critical loads for a two-week grid outage on larger bases. Microgrid systems can prioritize loads in real time and essentially can guarantee power availability for the highest priory critical load.

EDGs must be well-maintained if they are to be relied on for providing power for more than a few hours. If backup power is required for multiple days, stand-alone building-tied EDGs cannot be relied on by themselves to provide backup power for critical loads. Diesel generator based microgrid configurations provide a robust source of power for critical loads due to their network configuration. But microgrid do introduce other vulnerabilities that must be managed. These include cyber vulnerabilities and dependence on the on-campus distribution system. The analysis presented here also does not consider hybrid microgrid systems that combine EDGs with intermittent renewable energy and storage. In future work we will report on the reliability provided by intermittent renewable energy coupled to battery storage and the impact of the reliability of the on-base distribution system.

[12] System reliability is a measure of the likelihood that the critical loads will be supported for a required duration during a grid outage.

References

1. Marqusee, Jeffrey, Craig Schultz, and Dorothy Robyn. *Power Begins at Home:Assured Energy for U.S. Military Bases.* 2017. https://www.pewtrusts.org/~/media/assets/2017/01/ce_power_begins_at_home_assured_energy_for_us_military_bases.pdf.

2. U.S. Department of Defense. *National Defense Strategy.* Washington, D.C.: U.S. Department of Defense. 2018.

3. —. *2018 Annual Energy Management Report.* Washington, D.C.: U.S. Department of Defense. 2018.

4. Larsen, Peter, Kristina LaCommare, Joseph Eto, and James Sweeney. *Assessing Changes in the Reliability of the U.S. Electric Power System, LBNL - 188741.* Berkeley, CA: Lawrence Berkeley National Laboratory. 2015.

5. U.S. Department of Energy. *Multiyear Plan for Energy Cybersecurity.* Washington, D.C: U.S. Department of Energy. 2018.

6. Marqusee, Jeffrey, and Don Jenket. "Reliability of Emergency and Standby Diesel Generators: Impact on Energy Resiliency Solutions." 2020. *Applied Energy*, Vol. 268. 15 June 2020. 114918.

7. Birolini, Alessandro. *Reliability Engineering Theory and Practice.* New York: Springer, 2007.

8. 493, IEEE. *Design of Reliable Commercial Power Systems.* 2007.

9. 3000.6, IEEE Standard. *Recommended Practice for Anayzing Reliability Data For Equipment Used in Industrial and Commercial Power Systems.* 2018.

10. U.S. Department of the Army. *TM 5-698-5, Survey of Reliability and Availability Information for Power Distribution, Power Generation, and Heating, Ventilating and Air Conditioning (HVAC) Components for Commercial, Industrial and Utility Installations.* July 2006.

11. Du, Y., J. Burnett, and S.M. Chan. "Reliability of Standby Generators in Hong Kong Buildings." *IEEE Transactions on Industry Applications* 39 no. 6 (2003).

12. Thompson, Christopher C., Peyton S. Hale, Jr., and Robert G. Arno. "Decanting the Data: The Gold Book Presents Equipment Reliability Refreshment." *IEEE Transactions on Industry Application* 482 (2012).

13. Schroeder, John A. *Enhanced Component Performance Study: Emergency Diesel Generators 1998–2016*. INL/LTD 17-44204. April 2018.

14. Fehr, Stephen John. *Emergency Diesel-Electric Generator Set Maintenance and Test Periodicity.* Ph.D. diss., Old Dominion University. DOI: 10.25777/q2nk-n411 https://digitalcommons.odu.edu/emse_et, 2017.

15. National Fire Protection Association. *NFPA 110 Standard for Emergency and Standby Power Systems.* 2019.

16. U.S. Department of Defense. *Unified Fcility Criteria (UFC): OPERATION AND MAINTENANCE (O&M): GENERATORS.* Washington, D.C.: U.S. Department of Defense. 2018. UFC 3-540-07.

17. U.S. Nuclear Regulatory Commission. "Reactor Operational Experience Results and Databases." Last modified OCtober 1, 2019. https://nrcoe.inl.gov/resultsdb/.

Document Content(s)