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A Strategic Electrical Safety Pre-Plan

Initial Planning for Site-Wide Consolidation and Prioritization of Electrical Safety and Compliance Issues

Revision History		
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EXECUTIVE SUMMARY

This report provides Brookhaven National Laboratory (BNL) senior management a tool to aid in addressing identified electrical safety conditions using available resources with a systematic approach. The report is the result of the examination of a vast quantity of information extracted from assessments, hazard surveys, evaluation reports, and event databases related to electrical safety and regulatory compliance at BNL. Electrical safety issues were extracted, categorized, and ranked by a team that included: members of BNL's Safety Engineering Group, the Laboratory Electrical Safety Committee (LESC), Facilities & Operations (F&O) supervisory and electrical staff, Quality Management Office staff, and a National Fire Protection Association (NFPA) 70E and National Electrical Code (NEC) panel member. The report's approach is consistent with 10 CFR 851, *Worker Safety and Health Program*, which identifies workplace hazards and develops mitigation controls that consider safety of personnel with regard to shock and arc flash as a high priority.

By applying available resources to issues identified in the risk assessment tool as having the highest risk, the greatest benefit could be achieved with current funding. For corrective actions requiring capital expenditures beyond budget allowance, mitigation plans will be developed to control potential hazards until additional funding is obtained. Application of the proposed strategy does not guarantee items with lower ranking will not experience unanticipated failure. But, there will be a high level of confidence that failure of items of lower rank will not cause significant hazard exposure to people, property, or mission.

The tool considers operational impacts from risk to personnel and risk-to-mission perspectives, but not from a corrective action standpoint. Due to the significant costs of legacy building and infrastructure corrective actions, it is expected that the efforts to complete remediation across site will extend over multiple years. Further work with a broadly inclusive group from within BNL will be the next step to the development of a complete three-year action plan. Using this Strategic Plan as a starting point, this group will meet as necessary and mesh the remediation efforts with operational schedules and future BNL plans for buildings and programs. This strategic plan is structured to be a "living document" and updated as additional items and projects are identified and as projects are completed across BNL.

The team evaluated legacy issues that impact risk to workers, building occupants, buildings, programs, and regulatory compliance at BNL (See Appendix A for details). The initial work concentrated on legacy NEC non-compliance issues and evolved to consider overall Inspection, Test and Maintenance (ITM), as well as issues involving staffing, training, and procedure development. After extensive review of paperwork and discussions with staff, the team collected a comprehensive list of items that were then evaluated for electrical safety risk. The evaluation process used both quantitative and qualitative risk analysis incorporating data extracted from the Department of Energy (DOE) Health, Safety and Security monthly electrical incident reports over the last three years. The items were ranked within and across four categories. The four categories were prioritized as shown below:

1. Inspection Programs and Inspection/Test/Maintenance (ITM) issues
2. Group issues (e.g., training, work planning procedures, etc.)
3. Site-wide legacy Code issues (i.e., legacy Code issues in buildings where failure of the equipment would have site-wide impacts such as inaccurate panel schedules, unused openings in panels, etc.)
4. Building legacy Code issues (i.e., legacy Code issues in buildings where failure of the equipment would impact a single building such as inaccurate panel schedules, unused openings in panels, etc.)

Looking across the DOE Complex, the most common casual factor for electrical events occurs within the category defined as “Inspection Programs and ITM Issues.” At BNL, within this highest ranking category, inspection of new installations for Code compliance, and maintenance of protective devices operating above 250 Volts, are the two highest ranked activities. Improvement in both areas will reduce potential for continued risk and will require operational expenditures beyond what was currently funded in FY 2011.

In the past, BNL inspected and accepted new electrical installations; however, the process was not completely formalized. A formal program provides consistency of inspections, uniform qualifications of staff conducting inspections, and documentation for future audits and assessments. At the time of this report, a new formal program at BNL, the Electrical Materials and Equipment Installation (EMII) program, is operational; however the program will need to mature. A Chief Electrical Inspector has been hired to coordinate the program. The additional cost of finalizing the program is approximately $50,000. The cost of maintaining this program approximately will be approximately $200,000.00 per year (1.25 full-time employees [FTE]).

BNL, as with other older DOE sites, has not been able to consistently maintain circuit protective devices to a level that provides confidence that the arc flash analyses in all areas are accurate because the assumptions on the operation of the protective devices to specifications may not be correct. An effort to maintain 100% of the circuit protective devices immediately is unrealistic. So, the team developed a sophisticated approach to building risk assessment that has allowed the process to focus on the core facilities for BNL’s future science mission while insuring worker safety across the Laboratory. All buildings on site were analyzed, then narrowed down to 10 high priority buildings for final consideration and cost estimates. For these ten buildings, estimated cost for appropriate maintenance of about 2,175 protective devices as required by NFPA 70E within the higher hazard group (greater than 250 volts) is approximately $150,000 or one additional FTE per year.

The next highest ranked category, "Group Issues," emphasizes oversight of contractors in NFPA 70E, training of staff who oversee and inspect electrical installations, and formal training of the BNL line crew in the National Electrical Safety Code (NESC). NFPA 70E training for contractors is currently administered through BNL web-based training or acceptance of LESC-approved equivalent training for contractors with an added component for BNL specific requirements. Although the foundation for effective training programs has been established, gaps have been identified that if not corrected could contribute to a reduction in safety. The total estimated cost in time and material above current baseline is $400k over five years or $80k per year.

The third and fourth categories are building legacy Code issues. The specific legacy Code issues that rise to the top of the list are bonding and grounding non-compliances, inadequate signage for arc flash and high voltage, inaccurate panel schedules, and insufficient access control with signage to areas containing high voltage equipment.

As directed in 10 CFR 851, § 851.22(a)(2) and (b), Code issues that directly affect the safety of workers and staff are given a higher weighted value. The categorization process included two categories for Code issues to easily separate locations where equipment failure may cause a larger impact on operations and programs across the site. The team used a sophisticated approach to risk assessment to prioritize buildings for addressing the issues and the ten highest ranked buildings were selected for cost estimation. Additional efficiencies could be realized by combining the response to legacy Code issues with the over-current protective device maintenance effort. Yearly discussions with site planners and facility complex managers will be necessary to finalize the approach. These discussions will allow for integration of the ESSP elements into plans for any major renovations across site.

Based on the per-unit items currently identified, the total estimated cost to address each of the 10 highest risk facilities in five years is $12M or $2.4M per year. This investment would greatly reduce the risk of exposure to electrical hazards and non-compliance with electrical codes and standards in the 10 highest risk facilities in five years. Basis for cost estimates using building 490 as a model can be found in Appendix B. These cost estimates will be validated by BNL staff during FY 2012.

1. INTRODUCTION

a. PURPOSE OF THIS REPORT

The BNL Environment, Safety & Health Directorate (ES&H) commissioned this report to address electrical safety issues identified in audits, assessments, electrical hazard analysis reports, and gap analysis reports. This Strategic Plan report is intended to consolidate all currently identified issues and provide Lab Management a risk management tool that can be used to plan appropriate corrective actions with an emphasis on shock/arc flash events. This approach is consistent with 10 CFR 851, § 851.22.

This report will:

A. Identify and collect issues
B. Organize issues into understandable categories
C. Prioritize issues based on risk management principles
D. Bring forth the highest priority issues in each category
E. Develop a matrix showing the relative significance of each category
F. Discuss cost as related to priority
G. Identify areas requiring further investigation

b. BACKGROUND

Due to the significant costs of legacy building and infrastructure corrective actions, this study was commissioned to prioritize the legacy issues on a risk management basis and enable development of a strategy for resolution. In this report, critical infrastructure elements will be categorized apart from individual building issues. Risk to personnel, building, and program importance are the key factors in the quantitative rating of these buildings in this report.

BNL was developed on the grounds of a World War I and II military base (active from 1917 until 1920, and again from 1940 until 1946). These structures have electrical equipment and systems not installed to the Code of Record. Some electrical upgrades have occurred, but the systems do not meet current electrical installation standards or consensus codes in force at the time of installation. BNL’s critical programs generally are not housed in these older buildings but their scope does include some experimental areas, occupied offices, and residencies. Buildings have been identified for future demolition are of this era, but constitute a small percentage of the total older inventory. Much of the existing electrical wiring in these buildings is now well beyond the end of its service life.

Buildings constructed during the period of the 1950s to the1990’s are also not fully compliant to the Code of Record. This era of buildings contains many critical programs (e.g., Chemistry, Medical, Biology, Collider-Accelerator, NSLS I). Many of the buildings of this era are rated as the highest priority in risk.

Enhanced attention on acceptance of electrical installations has resulted in a high level of confidence by the LESC and ESH that new facilities constructed during the past ten years are compliant with the Code of Record (the NEC edition that was in effect at the time of design). Such buildings include Building 735 (Center for Functional Nanomaterials), and Building 400 (Research Support). However, some modifications made during this period are not fully Code compliant (as noted on Operational Readiness Evaluations)

Electrical Code requirements for new facilities are included in all phases of design and construction. Facilities currently planned for and in the process of construction at BNL (e.g., National Light Source II, and Interdisciplinary Science Building) are designed to comply with DOE requirements. Formalization of the EMII program will complete the process by documenting acceptance of the installation by the designated electrical inspector.

In the past, DOE Order 440.1A and DOE Order 420.1B provided the basis for electrical safety requirements. These requirements have existed for over 40 years in various forms.
In 2006, DOE instituted 10 CFR 851, *Worker Safety and Health Program*, which codified consensus codes and standards related to electrical safety, and added punitive action for non-compliance. In addition to ensuring legacy electrical issues were mitigated effectively, implementation of 10 CFR 851 presented a challenge to the Laboratory to determine which of the existing installations were compliant with applicable codes at the time of installation, which are subject to existing codes, and which are not in compliance but have been accepted by the delegated Authority Having Jurisdiction (AHJ) with restrictions on use.

c. APPROACH AND STRATEGY

The goal was to develop a strategy that will reduce the risk to the Laboratory from exposures related to deficiencies identified within the scope of the assessment. The evaluation team consisted of members of BNL's Safety Engineering Group, the Laboratory Electrical Safety Committee (LESC), F&O supervisory and electrical staff, Department Quality staff, and a National Fire Protection Association (NFPA) 70E and National Electrical Code (NEC) panel member. Data was collected from audit and assessment reports, hazard surveys, evaluation reports, and event databases related to electrical safety and regulatory compliance at BNL. Additionally, DOE Health, Safety, and Security (HSS) monthly electrical safety reports were reviewed to expand the sample of data for application of risk assessment methods. After extensive review of documentation and discussions with staff, a comprehensive list of electrical safety issues was compiled and categorized.

The team used both quantitative and qualitative risk analysis to rank each issue within and across the following four categories:

1. Inspection programs and ITM issues
2. Group issues (e.g., training, work planning procedures, etc.)
3. Site-wide legacy Code issues (i.e., legacy Code issues in buildings where failure of the equipment would have site-wide impacts such as inaccurate panel schedules, unused openings in panels, etc.)
4. Building legacy Code issues (i.e., legacy Code issues in buildings where failure of the equipment would impact a single building such as inaccurate panel schedules, unused openings in panels, etc.)

Following 10 CFR 851, paragraphs 21 and 22, the team evaluated legacy issues that impact risk to workers, building occupants, buildings, programs, and regulatory compliance at BNL. Although the initial review concentrated on legacy NEC non-compliance issues, the review evolved to consider overall ITM, as well as issues involving staffing, training, and procedure development.

From this review of past documentation, the team noted that the most common type of finding is Code non-compliance. Code deficiencies are identified routinely during assessments and Tier I safety inspections, and mainly involve electrical equipment or systems installed prior to implementation of 10 CFR 851. However, similar findings also exist in Operational Readiness Evaluation (ORE) reports conducted during the final stages of new construction and major renovation, indicating potential weaknesses in the current NEC compliance program. As a result, the group included inspection and training issues for those who work within the jurisdiction of the NEC to ensure Code compliance with future installations.

Discussions with members of the LESC revealed issues with the maintenance of circuit protective devices (e.g. circuit breakers), and with training of contractors in NFPA 70E. Proper maintenance is necessary to insure reliability of protective devices, a personnel safety issue. Training of all contractors on site is necessary to ensure work practices are conducted according to BNL requirements. It was concluded that ITM of existing electrical systems is a deferred maintenance issue that should be evaluated as part of this effort.

2. OVERVIEW OF ISSUES

The identified electrical safety and compliance issues cover a broad range. They can be broken down into three categories:

- Policy and Program issues. Policies and programs lay the groundwork for safe and compliant installation, acceptance, and maintenance of electrical systems;

- Group issues. These are the specific training, procedures, and work practices that provide staff with the knowledge to conduct their work safely; and
- Legacy equipment Code compliance. These issues are related to the physical installation of existing equipment. For the sake of this report, the team has separated legacy Code issues into those that might affect larger portions of the laboratory from those that would affect only one building.

Requirements for these issues are found in NFPA 70E, the *Standard for Electrical Safety in the Workplace*, NFPA 70, *National Electrical Code*, OSHA 29CFR1910, *General Industry*, and OSHA 29CFR1926, *Construction*. A comprehensive electrical safety strategic plan must include an analysis of issues within these categories and also an analysis of the inter-relation of the categories.

a. POLICIES AND PROGRAMS

i. POLICIES

BNL's robust policies for electrical safety are contained within the Standards Based Management System (SBMS) and comply with DOE requirements. The Electrical Safety Subject Area in SBMS provides procedures and requirements which are readily accessible online and provide contact information to a subject matter expert (SME). Maintenance of SBMS is funded through Operations.

ii. PROGRAMS

Typically, issues related to electrical safety programs would be funded through Operations; however, program development could be funded through other means.

iii. ACCEPTANCE PROGRAMS

The results of the risk analysis rated Acceptance Programs high in priority. BNL has taken a pro-active approach over the last several years to enhance electrical safety and compliance by establishing two programs.

The Electrical Equipment Inspection (EEI) project was established in 2005 to systematically accept non-listed equipment at BNL, and resulted in an extensive evaluation of stored and in-use older electrical equipment with over 40,000 items listed in the current database. Many pieces of older equipment that failed inspection were discarded. The EEI project was completed in 2009, and the EEI program was instituted at BNL to accept new purchases and newly built equipment.

A companion to the EEI program, the Electrical Materials and Installation Inspection (EMII) program, is designed to formally accept electrical installations. Over the years at BNL, it has been noted that some electrical distribution installations do not have formal documentation of acceptance by the AHJ. The lack of formal inspection and associated documentation is one cause of legacy Code deficiencies related to electrical installations. The EMII program is presently operational but will require expenditure over the next year (FY 2012) to finalize the inspection documentation process. It is expected that this program will greatly enhance the Code compliance of new installations. With a formal program to accept new electrical installations in place at BNL, we can begin to address the legacy Code issues commonly identified in assessments.

To demonstrate the need for an effective NEC enforcement program, the team compared the electrical installations in three separate facilities: Building 400, a new construction project; Building 600, a recent major modification; and Building 490, an older facility with minor maintenance and modifications. (A complete report of the comparison can be found in Appendix C.). In summary, Building 400, which had a dedicated third-party electrical inspection service, had no NEC violations noted and the workmanship was noteworthy. Building 600, which had interim NEC inspection support, contained significant NEC non-compliance examples that will either require remediation with a cost into the six-figure range or for BNL to assume liability through equivalencies and deviation allowances. Building 490 had numerous and significant non-compliance issues with both the NEC and OSHA for not only the older installations, but also with new minor modifications of the electrical distribution system. It is evident that some electrical work conducted in Building 490 was not reviewed and inspected by competent third-party electrical inspectors.

iv. INSPECTION, TEST, AND MAINTENANCE PROGRAMS

Equipment maintenance has been noted by the LESC as a possible area of investigation for this report. A formal equipment maintenance program does not presently exist for many over-current devices and other equipment. The analysis placed a high priority on over-current device maintenance that operates in higher hazard levels (above 250 Volts). Typically, a preventative maintenance program would be funded through operations. At a lower priority is maintenance of over-current devices operating under 250 Volts.

b. GROUP ISSUES

i. TRAINING

Electrical training at BNL has evolved over the years and is mature. Electrical safety training for staff and contractors is fulfilled by a combination of Lab-wide Computer-Based Training (CBT) and department-specific training. The level of training is consistent with the potential exposure related to the level of work. The following list of courses illustrates how the investment is commensurate with the risk. Each of the courses listed below is presented in CBT format and increases in complexity in accordance with the risk of the work involved:

- Basic Electrical Safety is required for non-electrical workers who may work with, or come in contact with, de-energized, electrically powered devices.
- Electrical Safety for Benchtop Workers is required for workers whose electrical work is limited to 120-Volt, line-cord, plug-in equipment.
- Electrical Safety I is required for electrical workers who work On or Near exposed energized parts (NFPA 70E Risk Hazard Category 1 or higher). This course is also required for staff who direct and evaluate electrical work.
- Lockout/Tagout for the Affected Worker is required for personnel who work in the vicinity of locked/tagged equipment or who operate machinery on which maintenance, services, or construction is being performed under Lockout or Tagout. An affected employee cannot add or remove a lock or tag.
- Lockout/Tagout: Non-Electrical Authorized Employee is required for anyone who needs to lockout/tagout equipment, but who does not work on exposed electrical terminals or components, energized or non-energized. In addition, they must complete department-specific training.
- Lockout/Tagout: for the Authorized Worker is required for staff who need to lock and tag mechanical or electrical energy sources. In addition, they must complete department-specific training. Electrical Safety I is a prerequisite for this course, unless the equipment being locked/tagged is not electrical (e.g., hydraulic, pneumatic).

Safety and Health Services, the Training and Qualifications Office, and LESC were instrumental in initiating training for those whose work falls within the requirements of the NEC. Also, on a case-by-case basis, the LESC has reviewed and approved equivalent NEC and NFPA 70E training for electrical contractors, when the contractor can demonstrate that BNL training goals have been met. The training programs are funded through operations.

One area that will require a higher degree of formalization is training for contractors that apply LOTO; specifically the LESC noted this possible gap with contractors who provide maintenance under contracts. At the present time, there is no formal mechanism for recording the completed training of these individuals. Since 70E training is listed as a high-ranking area of improvement, this issue needs to be addressed and investigated further. The issue was brought up late in the development of this report and will require further investigation. One potential action to address this issue is to coordinate with Procurement to ensure a level of competency before awarding contracts for work on or around energized electrical equipment.

At a slightly lower level of priority is formal training for workers that do electrical work on systems operating above 600 Volts. The review team considers work at this voltage some of the highest hazard work conducted at BNL.

Other areas using the risk assessment approach strategy which need additional attention include the following:

- Training was conducted in 2007, for those who will perform electrical inspections under the newly developed EMII program will need to be conducted again at every Code cycle. Code update seminars will provide the inspectors with the latest information related to the NEC. This training conducted by an outside company is expected to cost about $20k every three years.

- Training for the Line Crew is also ranked high in the analysis. The requirements that apply to Line Crew work are contained within the NESC. Presently, formal training in the NESC (IEEE-C2) is not offered at BNL. It would cost approximately $10k every Code cycle (5 Years) to train Line Crew members in the requirements of the NESC by an outside company.

c. EQUIPMENT INSTALLATION LEGACY CODE ISSUES

i. NEW FACILITY CONSTRUCTION

Electrical Code requirements for new facilities are included in all phases of design and construction. Facilities currently planned for and in the process of construction at BNL (e.g., National Light Source II, and Interdisciplinary Science Building) are designed to comply with DOE requirements. Formalization of the EMII program will complete the process by documenting acceptance of the installation by the designated electrical inspector.

ii. EXISTING MODERN FACILITIES

Enhanced attention on acceptance of electrical installations (such as including a dedicated NEC inspector) has resulted in a high level of confidence by the LESC and ESH that facilities constructed during the past ten years are compliant with the Code of Record (the NEC edition that was in effect at the time of design). These buildings account for approximately 15% of the total existing campus building square footage. Such buildings include Building 735 (Center for Functional Nanomaterials), Building 400 (Research Support), and Building 817 (Office Addition).

iii. OLDER BUILDINGS AND LEGACY ISSUES

Existing structures that are 10 years old or older, 85% by square footage, were constructed before 2000. These buildings contain distribution system and experimental equipment installations that do not comply with the Code of Record. Through the years, BNL has modified these buildings as needed for experimental and infrastructure upgrades. These modifications have resulted in additional Code non-compliance issues such as insufficient space in front of electrical panels, unused openings in electrical equipment, improper hardware used to secure panel covers, overfilled cable trays, and inaccurate disconnect identification.

The critical programs housed in these older buildings include the following facilities: 200 MeV Linac and Collider Accelerator Department (CAD), Chemistry, Medical, NSLS I, Physics, and Biology, as well as occupied offices and residential occupancies. Buildings identified for future demolition are of this era, but constitute a small percentage of the total older inventory. Much of the existing site electrical infrastructure elements within these buildings are also of this era; some are over-dutied and some may be well beyond the service life expectancy. Some of the site infrastructure components that feed these buildings are also older. Site infrastructure is unique since a failure can adversely affect many buildings and programs in one event. In this report, critical site infrastructure elements will be categorized separately from building issues.

Electrical safety issues associated with these buildings have been identified and projects have been initiated for remediation. Some of these projects have been running for several years with intermittent funding. Additional issues were added in the developing this report.

Information on the relevant legacy issues were obtained from gap analysis evaluations, baseline needs assessment compliance reviews, evaluation of current electrical safety projects, evaluation of current electrical safety programs, BHSO assessments, and the past evaluation of Part 851 compliance. Detailed studies like those completed over the years for the Fire Safety Strategic Plan do not exist and some scoping projects will be needed to identify specific needs within these older buildings. This report identifies the recommended order in which to address the buildings and provides a rough cost estimate for addressing the previously identified deficiencies. The basis for the cost estimate is attached as Appendix B.

Each year an inclusive group from Brookhaven will adjust the specific plan for the next several fiscal years. It is expected that while the group considers future BNL plans for buildings and programs, it will identify items within these buildings that if remediated during renovation will provide a high risk reduction/cost ratio. This Strategic Plan was designed to be a living document and if additional items are identified during these interactions, the plan allows for smooth integration of the risk analysis and prioritization of these items.

3. ADDRESSING THE ISSUES

a. APPROACH

Based on the nature of the issues, their impact on safety, the facility, and programs at BNL, the priority items that are summarized in Section 2 of this report were highlighted using the Risk Analysis Tool (Appendix A). By addressing the highest priority issues, the risk for loss or injury will be reduced significantly. Lower priority issues would be addressed on a longer term schedule or as operating expense work orders, as manpower and funds become available. Although the risk of failure by components of lower priority will remain, the adverse effects of such failure will have less consequence than failure of higher priority items.

It is important to note that it would be neither cost effective nor safer to consider items independently or address higher priority items serially. Several other factors require management decisions that cannot be implemented into the Risk Analysis Tool. Such factors include: available resources, multiple budget periods projects, emergent events, and changing mission conditions.

The four-step approach for developing this analysis is:

i. Identify the Issues

Issues were identified that relate to the compliance with contract and regulatory requirements. Items found in past audits, gap analysis reports, Tier I reports, Occupational Readiness Evaluations, and internal BNL reviews have been considered. The items were reviewed for current relevancy and redundancy. Ultimately, the team listed 25 items that met the established criteria.

ii. Categorize the Issues

Based on a review of the identified issues, the following categories (bins) were selected for organizing the review

a. ACCEPTANCE and ITM ISSUES (i.e.: new installation inspection and acceptance and maintaining installed electrical systems)
b. ELECTRICAL WORKER GROUP ISSUES (i.e.: policies, training, staffing, and equipment)
c. SITE-WIDE ISSUES (i.e.: legacy code deficiencies that effect multiple buildings)
c. BUILDING ISSUES (i.e.: Code deficiencies, overdutied equipment, aged equipment, etc.)

iii. Prioritization within Categories

Within each category, issues were ranked using a Semi-Quantitative Risk Ranking (SQRR) method using information from established hazard analysis tools and databases. As an example, to rank one building against another when considering the safety of those who work on the equipment, the following process was followed. A base risk for working on equipment was first established using the standard components of severity and probability. The level of hazard within voltage groups was identified using hazard chart 2 for 60 Hz equipment from EFCOG's Electrical Severity Measurement Tool. Relative probability was assigned using events captured in the Health, Safety and Security (HSS) electrical safety monthly reports. Next, for each voltage group, the number of equipment in each building was combined in a weighted sum based on the relative risk assigned in the previous step. Then, this amount was combined with the likelihood of finding Code issues within each building. The result was a prioritized list based on risk as determined by the hazard, probability, frequency of interaction with equipment and likelihood of finding Code issues.

Regarding the order in which to address Code deficiencies within the buildings, the increased level of hazard presented by each Code deficiency was evaluated relative to one another by a group of Subject Matter Experts (SME's). In compliance with 10 CFR 851, consideration was given to the risk components in the priority listed below.

1. Risk to worker performing work
2. Risk to other staff (building occupants)
3. Risk to building (replacement)
4. Compliance risk
5. Risk to program (mission)

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For each Code deficiency, a relative number was assigned to each risk component with an emphasis put on personnel safety. Then a sum was calculated from the component parts.

Electrical risk to others within the building was evaluated in much the same way and included an occupancy type and occupancy duration term. Occupancy types included staff, general public, and children. A Code deficiency such as unused openings in an area accessible to children was given a higher risk rating than the same deficiency within an area accessible only to qualified personnel.

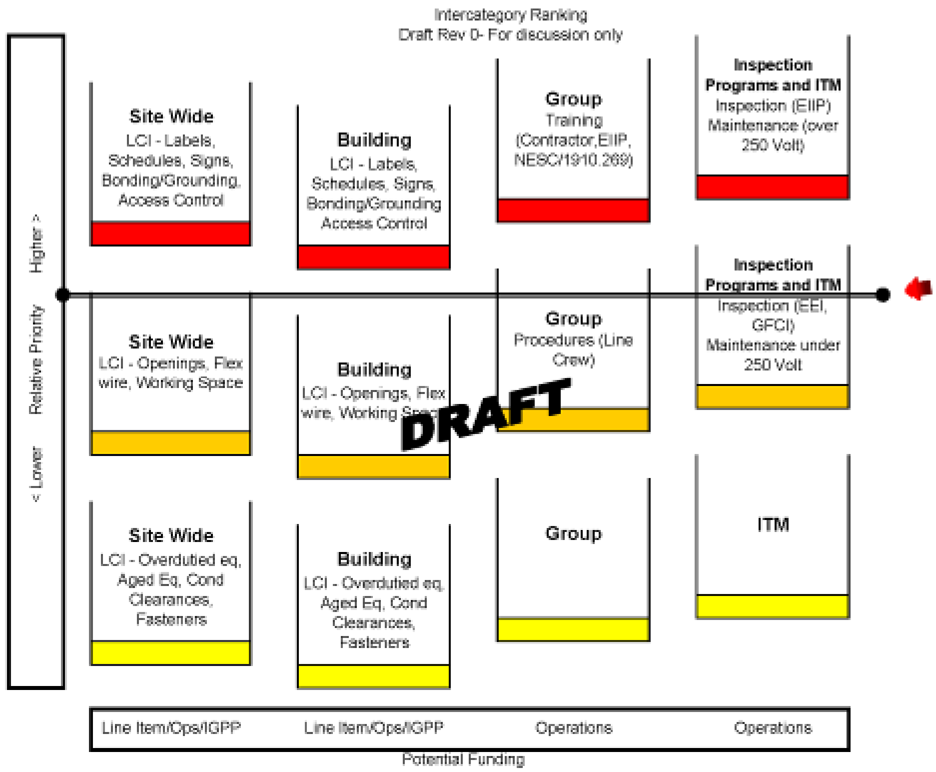
The team strived to apply the process consistently with all categories. Although not purely quantitative, the ranking does reflect the relative importance and priority rating.

Based on both quantitative and qualitative factors, issues were divided into compliance color codes. Following traditional RED-YELLOW-GREEN priority ratings in management reports, the highest priority items are in the RED category, followed by YELLOW, and then GREEN. The following shows a portion of the spreadsheet that includes the 10 highest priority buildings evaluated for risk to workers.

BLDG #	Building Name	Risk To Qualified Worker Total	Risk To Building Occupants Total	Risk to Building Programmatic Total	Risk to Building Cost Total	Compliance Risk Total
490	Medical Research Center	1345601	2568875	3	1345601	6780
902	Magnet Div., LightSource II, Quality Mgt	1091953	1091953	3	1091953	4830
555	Chemistry	936563	1787984	3	936563	4120
911	Collider Accelerator Department	809669	2281796	3	809669	3470
930	200 Mev Linac	717235	717235	3	717235	3050
703	Lab/Office Building	711723	1358744	3	711723	3150
510	Physics	653585	1247754	3	653585	3900
535	Instrumentation Division	646742	1234689	3	646742	3480
463	Biology	555963	1061384	3	555963	4150
815	GARS / ELS Multiprogram Laboratory	505004	505004	3	505004	2180
901	Radioisotope and Radiotracer C	472873	472873	3	472873	2100
801	Isotope Research and Processing	464733	887217	3	464733	1950
901A	Van De Graaff Building	415221	1170168	3	415221	1700

iv. Prioritization across Categories

This section addresses the relationship of priorities between the four categories. Due to the nature of the site-wide category issues, the RED issues in this category have a higher impact than issues in individual buildings. Inter-category rankings are based on numbers of events of a particular type, captured in the HSS electrical monthly reports.



4. CONCLUSIONS

Since 2005, BNL has continually improved its awareness of electrical safety at the Laboratory. Policies, programs, and procedures have been instituted dedicated to the goal of reducing exposures of people and property to hazards associated with electrical energy. These efforts have resulted in a foundation that, if continued to be supported, will place BNL in a class that can compete with any program in the DOE complex, and certainly general industry. Some programs, such as the SBMS, EEI, and site worker training courses, are very mature and continue to result in fewer electrical safety incidents. Other programs, such as the EMII, still have some work outstanding before they reach full fruition.

Although elements are in place or in development that will ensure future installations are safe and compliant, legacy conditions continue to be a concern. There is no objective evidence to provide assurance that past installations were compliant with industry accepted consensus codes and standards or some recognized equivalent. Additionally, there is evidence that much electrical equipment and systems installed prior to 2005 have not been maintained adequately so that the results of electrical safety analyses for these locations are questionable. Many mission critical activities are conducted in facilities where this equipment is located.

Much of the electrical equipment and systems in original Laboratory buildings has exceeded its service life, with no compensatory actions to mitigate the risk associated with this condition. It is noted that risk of fire with these energized systems do pose a hazard to the property. Within the scope of the ESSP which considers mitigating factors (e.g., fire protection systems), personnel safety with regard to shock/arc flash inherently ranks higher than the personnel risk from an electrical fire.

It is impractical to assume that funding and resources will be available immediately to address the thousands of potential issues identified in this report. A systematic approach must be applied to determine where to focus available resources to ensure maximum safety and efficiency. This effort must be combined with mitigating actions to reduce risk and exposure to an acceptable level for those locations not corrected with permanent actions. Corrective actions must include consideration of operational impacts, not only from existing conditions but also when developing corrective actions. Some deficiencies will require multi-year contracts to completely address the associated issues. Meanwhile, the affected systems could be mission critical, requiring innovative alternative methods to maintain operations.

5. RECOMMENDATIONS

The Risk Analysis Strategy attached as Appendix A was developed by a group of technical SME's. The group used their collective experience and knowledge to produce a tool that provides a semi-qualitative method to prioritize electrical safety issues from a risk avoidance perspective. The approach is semi-quantitative due to the fact that subjective factors were included that consider personnel safety, customer perspective, and extent of conditions to complete the process. The group is confident that if the strategy is applied, Lab management will maximize efficiency and results in an attempt to address the identified electrical safety issues.

By applying available resources to issues identified in the risk assessment tool as having the highest risk, greatest benefit could be achieved with current funding. For corrective actions requiring capital expenditures beyond budget allowance, mitigation plans will need to be developed that will control potential hazards until additional funding is obtained. Application of the proposed strategy does not guarantee items with lower ranking will not experience unanticipated failure. But, there will be a high level of confidence that failure of items of lower rank will not cause significant hazard exposure to people, property, or mission.

The tool considers operational impacts from a risk-to-mission perspective, but not from a corrective action standpoint. Further work with a broadly inclusive group from within Borrkhaven will be the next step to the development of a complete action plan. Due to the significant costs of legacy building and infrastructure corrective actions, it is expected that the efforts to complete remediation across site will extend over multiple years. This strategic plan is intended to be a "living document" and updated as projects are completed across BNL. Close interaction with facility complex managers will be required to mesh the remediation efforts with operational schedules.

The team has provided the basis for a rough-order-of-magnitude (ROM) cost estimate necessary to implement corrections to the 10 highest ranked facilities. The method used to arrive at this estimate used the highest ranked facility, Building 490, as the model and expanded the sample to other facilities. The cost was assumed as a per-unit value for each of the electrical devices rated at greater than 250 volts, since those provided the greatest exposure according to the tool. The team considered a five-year project to fully implement all recommendations in each of the four categories, combining the last two with an equipment replacement effort.

The details are provided in Appendix B, but the summary of costs is as follows:

1. The total cost to implement corrective actions in the area of Inspection, Testing, and Maintenance; excluding the funds already committed for a Chief Electrical Inspector is $400k or $80k per year.
2. The total cost to provide the training necessary to fill gaps noted in the existing training and procedure programs is $400k or $80k per year.
3. The total estimated cost to make the necessary modifications that will bring the facilities into compliance with installation rules is $12M or $2.4M per year.

Total estimated cost for all categories is $12.8M or $2.6M per year.

Appendix A

Risk Assessment Tool

The Electrical Safety Risk Assessment Tool was developed with input from members of BNL's Safety Engineering Group, the Laboratory Electrical Safety Committee (LESC), F&O supervisory and electrical staff, Department Quality staff, and a National Fire Protection Association (NFPA) 70E and National Electrical Code (NEC) panel member. The approach is consistent with direction described in 10 CFR 851, *Worker Safety and Health Program*, to identify workplace hazards and develop mitigation controls that consider safety of personnel as a first priority. Contractor and BNL Subject Matter Experts analyzed HSS and BNL databases, extracted Data for type, hazard severity, probability, exposure frequency and comparatively ranked deficiencies with respect to risk to staff within and across three major categories of deficiencies. The information was tabulated in a spreadsheet used to process the information and order the items. Output from the spreadsheet analysis is presented below.

The tables can be used for comparing the safety aspects of compliance issues at BNL. It is intended to give staff a starting point for prioritizing electrical safety projects/programs and group issues at BNL. The process emphasized the importance of providing a safe workplace to the worker and other staff related to shock events/arc flash. Events that might result in fire will inherently rank lower in the electrically strategic plan due to the robust fire protection systems in place across site. Building replacement cost and compliance are also considered but given a lower weight in the ESSP. Staff involved in developing a specific three years plan can use the tables to help order the items and buildings to be addressed within and across the categories. Headings and ratings for the tables are defined below.

<u>SME Evaluation of Risk - Definitions</u>
RTQW - Risk to Qualified Worker
RTBO - Risk to Building Occupants/ Unqualified worker
RTB – Risk To Building
CR - Compliance Risk

<u>SME Evaluation of Risk</u>
0 - No added risk
1 - Minimal added risk
2 - Moderate added risk
3 - Significant added risk

<u>SME Evaluation of BNL Program Maturity (IP) –Risk Mitigation</u>
1 - Formal program in place
2 - Informal or unvalidated or incomplete program in place
3 - Program not in place

Tables for comparing similar issues

The following tables order compliance deficiencies with regard to safety at BNL. SMEs considered risk to workers, staff, building and compliance with consideration for safety of people given the highest weight. Where applicable, SMEs evaluated the maturity of BNL procedures and programs currently implemented to mitigate the risks. The priority of the issue is displayed in a red/yellow/green dashboard format.

Inspection Program/ITM Priority Worksheet

	RTQW	RTBO/UQW	RTB	CR	Risk Total (RT)	In place (IP)	Dashboard
Inspection Programs							
EEIP	5	0	2	10	17	1	Green
EMIIP	15	15	6	10	46	2	Red
Testing Programs							
GFCI	0	15	0	10	25	2	Yellow
Inspection/test/maintenance							
Equipment over 600 Volts							
Protective Devices	50	5	6	10	71	2	Red
All Other	5	0	6	1	12	2	Green
Equipment 250 to 600 Volts							
Protective Devices	50	5	6	10	71	2	Red
All Other	5	0	6	1	12	2	Green
Equipment below 250 Volts							
Protective Devices	15	5	2	10	32	2	Yellow
All Other	5	0	2	1	8	2	Green

Group Issues – (training, procedures, etc.)

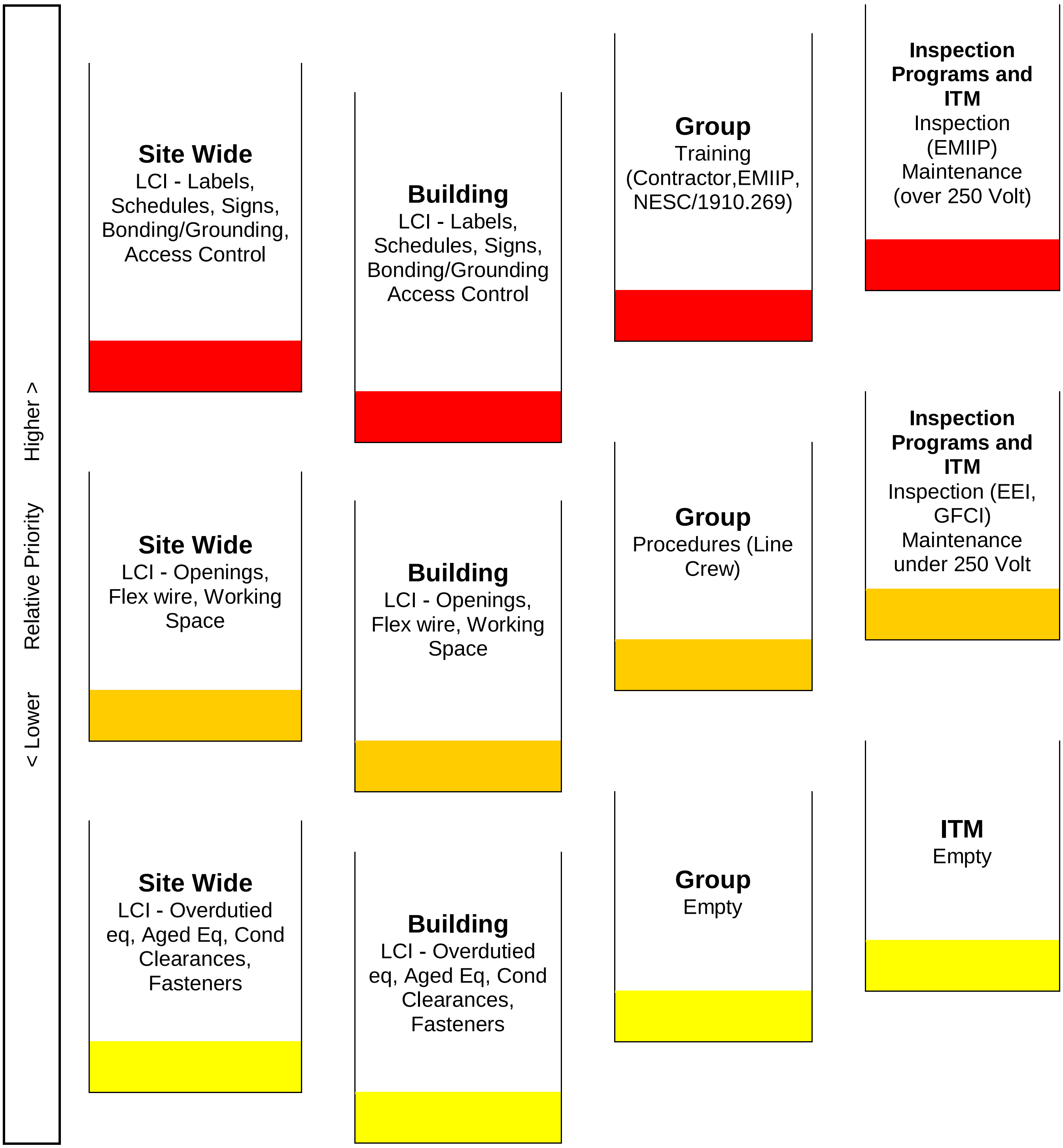
Group Relative Priority Worksheet

	RTQW	RTBO/UQW	RTB	CR	Risk Total (RT)	In place (IP)	Dashboard
Training							
Separate NFPA 70 Base/Update	15	15	6	1	37	1	
Separate NFPA 70E Base/Update	5	5	0	0	10	3	
Separate NESC/269	50	0	2	1	53	3	
BNL Basic Electrical Safety	0	15	0	10	25	1	
Electrical Safety I	50	15	0	10	75	1	
BNL LOTO	50	15	0	10	75	1	
BNL Switch Thrower	15	5	0	1	21	1	
Contractor Training	50	15	0	10	75	2	
Procedures							
Line Crew Procedures	50	5	2	1	58	2	

<u>Legacy Code Issues Used for Single Building and Site-Wide application</u>

Legacy Issue Priority Worksheet					
Issue	RTQW	RTBO/UQW	RTB	CR	Dashboard
Overdutied Equipment	5	0	6	2	
Above Cat 4 Equipment	5	0	2	0	
Labels/Schedules/Signs	50	15	0	6	
Unplugged openings	5	5	2	6	
Cable Tray B/G, Abandoned and Structural	15	5	6	6	
Stationary grounds	50	0	0	20	
Fencing /locked doors	5	50	0	20	
Aged Equipment	15	0	2	0	
Flexible wiring use (Distribution)	5	0	2	20	
Mounting screws	5	0	0	6	
Working space	15	0	0	20	
Conductor clearances	5	0	0	3	

Comparison Across categories



Building Priority

BLDG #	Building Name	RTW Total	RTBO Total	Building Programmatic Total	Building Cost Total	Compliance Total
490	Medical Research Center	1345601	2568875	3	1345601	6780
902	Magnet Div., LightSource II, Quality Mgt	1091953	1091953	3	1091953	4830
555	Chemistry	936563	1787984	3	936563	4120
911	Collider Accelerator Department	809669	2281796	3	809669	3470
930	200 Mev Linac	717235	717235	3	717235	3050
703	Lab/Office Building	711723	1358744	3	711723	3150
510	Physics	653585	1247754	3	653585	3900
535	Instrumentation Division	646742	1234689	3	646742	3480
463	Biology	555963	1061384	3	555963	4150
815	GARS / ELS Multiprogram Laboratory	505004	505004	3	505004	2180
901	Radioisotope and Radiotracer C	472873	472873	3	472873	2100
801	Isotope Research and Processing	464733	887217	3	464733	1950
901A	Van De Graaff Building	415221	1170168	3	415221	1700

Appendix B

Cost Estimate Basis

Building 490 was used as the baseline model to estimate costs in each of the categories considered. Since equipment rated greater than 250 volts was determined by the tool to present the greatest risk, only equipment in that range was considered. However, where replacement of equipment below the 250 volt threshold appeared to provide major benefit for reasonable cost to enable replacement of larger equipment, or provide a significant safety improvement, the itemized estimate is provided. The estimates can be expanded with this basis to include other buildings and equipment. A per-unit value can be applied to provide a reasonable estimate for planning purposes. Five years is the duration considered to address the hazards in Building 490 to an acceptable level using the risk analysis tool. The cost per hour of the labor is assumed at $100.00. The total estimated cost to implement the recommendations to Building 490 is approximately $1.8M over five years or $360k per year.

A. INSPECTION, MAINTENANCE, & TESTING >250 VOLTS

This category includes inspection of new or modified installations for Code compliance, maintaining equipment to a safe and compliant level, and testing equipment to ensure performance is maintained to an acceptable tolerance.

- NEC inspections will be performed on all installations considered in Section B. The estimated hours spent on NEC and an equipment-acceptance inspection is 40 per year for a total annual cost of $4,000.00.
- Maintenance and testing of electrical equipment is consolidated for estimating purposes. Some equipment will require removal and calibration, while others will require simple cleaning and visual inspection. The average time estimated to maintain and test each of the 342 items considered is 4 man-hours over five-year duration. The normalized per-year cost to maintain the equipment is estimated at $30,000.00.

B. TRAINING AND PROCEDURES

Training and procedures are already considered in the Laboratory baseline. The estimate provided here is to address the identified gaps in the current program as well as consider training and procedure support necessary if the recommendations are accepted. Typical certification agencies consider a minimum of 8 hours each of continuing education necessary to maintain proficiency of a qualification. This estimate assumes 12 hours per year for each additional FTE to account for site-specific training and procedure support. Quality training can be obtained at a cost of $350.00 per student per day. Considering the additional site costs, the assumed annual cost per FTE is $500.00.

Using the estimates for maintenance in A and modifications in C, the total number of hours devoted to this training over five years is approximately 8500 or 1 FTE per year. So, the estimated total additional cost of training is $62,500.00 or $12,500.00 per year.

C. LEGACY CODE ISSUES AND AGED EQUIPMENT

The attached estimate details replacement cost for one 480 volt feeder (Bus #4) for Building 490. This replacement will correct several legacy Code issues and update equipment well passed the end of its reliable service life. The number of items operating at greater than 250 volts addressed in this estimate represents approximately 10% of the total identified for Building 490. Using the per-unit method, the total cost to bring the building electrical distribution system into full compliance within five years is $1.65M or $350k each year.

Although much of the equipment identified as needing replacement falls below the 250 volt threshold established by the tool as less priority, replacing the associated equipment will correct many safety issues in the lower voltage system. Additionally, updating the equipment simultaneous with the 480 volt equipment will realize substantial savings in efficiency and cost.

Estimate to Replace Bus #4

Section	Size	Item Desc	Qty	UOM	Mat Unit	Mat Adj	Mat Ext	Lbr Unit	Lbr Adj	Lbr Ext
Section 004: FEEDER - FEEDERS	2"	X 12 NIPPLE	32	EACH	$47.14	1	$1,508.59	0.6	1	19.2
Section 004: FEEDER - FEEDERS	2"	LOCKNUT	128	EACH	$2.63	1	$336.91	0.8	1	102.4
Section 004: FEEDER - FEEDERS	2"	PLASTIC BUSHINGS	64	EACH	$3.92	1	$251.03	0.8	1	51.2
Section 004: FEEDER - FEEDERS	3/8.	FLAT WASHER	60	EACH	$0.10	1	$6.00	Skip	1	0
Section 004: FEEDER - FEEDERS	3/8.	HEX NUTS	60	EACH	$0.13	1	$7.76	0.1	1	6
Section 004: FEEDER - FEEDERS		CHANNEL 12GA 1-5/8"	50	FEET	$6.43	1	$321.42	0.12	1	6
Section 004: FEEDER - FEEDERS	3/8.	ALL THREAD ROD	100	FEET	$0.75	1	$75.00	0.12	1	12
Section 004: FEEDER - FEEDERS		18X18X6 HNG-CVR BOX	16	EACH	$107.90	1	$1,726.40	1.9	1	30.4

Section 004: FEEDER - FEEDERS	12	THHN SOL CU	1,500.00	FEET	$0.25	1	$379.89	0.006	1	9
Section 004: FEEDER - FEEDERS	6	THHN STR CU	3,500.00	FEET	$1.18	1	$4,132.56	0.011	1	38.5
Section 004: FEEDER - FEEDERS	1/0	THHN STR CU	400	FEET	$4.65	1	$1,858.04	0.022	1	8.8
Section 004: FEEDER - FEEDERS	400	THHN STR CU	800	FEET	$16.99	1	$13,592.96	0.041	1	32.8
Section 004: FEEDER - FEEDERS	500	THHN STR CU	75	FEET	$21.05	1	$1,578.42	0.044	1	3.3
Section 004: FEEDER - FEEDERS		12CKT TERM BLOCK	64	EACH	$8.25	1	$528.00	0.3	1	19.2
Section 004: FEEDER - FEEDERS	#10-1/0	3W TERM BLOCK	16	EACH	$14.00	1	$224.00	0.4	1	6.4
Section 004: FEEDER - FEEDERS	12X12X1	WIREWAY	120	EACH	$37.10	1	$4,452.00	0.33	1	39.6
Section 004: FEEDER - FEEDERS	12X12	WIREWAY END CAP	2	EACH	$22.97	1	$45.94	0.3	1	0.6
Section 004: FEEDER - FEEDERS	12X12	WIREWAY COUPLING	12	EACH	$30.56	1	$366.72	0.5	1	6
Section 004: FEEDER - FEEDERS	12X12	WIREWAY TEE	1	EACH	$192.72	1	$192.72	0.7	1	0.7
Section 004: FEEDER - FEEDERS	12X12	WIREWAY PANEL CONN	1	EACH	$50.16	1	$50.16	0.6	1	0.6
Section 004: FEEDER - FEEDERS		Subtotal					$31,634.50			353.1
Section 005: SWGR/PNL - SWITCHGEAR & PANELS	125A	24 CIRCUIT-PANEL BD	4	EACH	$1,015.00	1	$4,060.00	10.76	1	43.04
Section 005: SWGR/PNL - SWITCHGEAR & PANELS	150A	24 CIRCUIT-PANEL BD	11	EACH	$1,015.00	1	$11,165.00	10.96	1	120.56
Section 005: SWGR/PNL - SWITCHGEAR & PANELS	225A	42 CIRCUIT-PANEL BD	1	EACH	$1,015.00	1	$1,015.00	17.4	1	17.4
Section 005: SWGR/PNL - SWITCHGEAR & PANELS	400A	32 CIRCUIT-PANEL BD	2	EACH	$1,045.00	1	$2,090.00	15.68	1	31.36
Section 005: SWGR/PNL - SWITCHGEAR & PANELS	150	3PH TRANSFORMERS	2	EACH	$3,735.00	1	$7,470.00	20	1	40
Section 005: SWGR/PNL - SWITCHGEAR & PANELS	200A	HD 3PNF 600V NEMA 1	1	EACH	$683.09	1	$683.09	7	1	7
Section 005: SWGR/PNL - SWITCHGEAR & PANELS		Subtotal					$26,483.09			259.36
		GRAND TOTAL					$58,117.59			652.06

Material Total : $58,117.59										
Labor Total : $66,510.00										
Demolition and Waste Handling Total :$10,000.00 Design and Engineering Total :$30,000.00										
Estimate Total : $ 164,650.00										
Exclusions: Core drilling, electrical permit, sales tax, bonding, ETC.										

Appendix C

Code Compliance Comparison

The team conducted a brief assessment of three buildings to determine the effectiveness of NEC and OSHA compliance with varying degrees of independent oversight. The buildings reviewed are:

1. Building 400, a new construction project that was occupied in 2007. The construction project included a dedicated NEC inspector that reported to the BNL Engineering Group and was independent from the Architect/Engineer and General Contractor.
2. Building 600, a major modification project, that did not include NEC inspection until issues were identified that generated the addition of an NEC inspector that reported to and was paid by the construction contractor.
3. Building 490, and operating facility that experiences minor modification and maintenance to an existing distribution system with little or no electrical inspection enforcement. Work performed within Building 490 is conducted by both plant forces and construction forces.

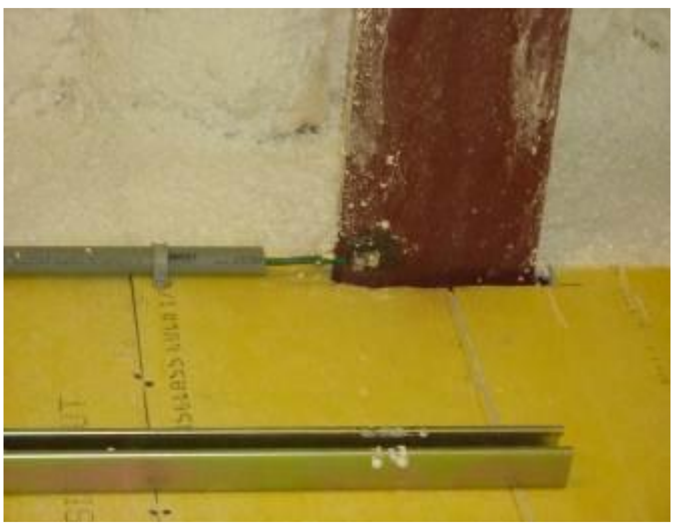
A. <u>Building 400</u>

During the assessment of Building 400 the team was unable to identify any examples of non-compliance with mandatory electrical codes or standards. The workmanship is impeccable. Common issues that plague other facilities on site such as inadequate working clearance, encroachment of dedicated space, non-compliance with emergency system wiring is not present in Building 400. Below is a series of pictures that demonstrates the effectiveness of a dedicated third-party inspector.

Picture A1. Proper grounding and bonding of the electrical distribution system.

Picture A2. Panel schedule complete and accurate.

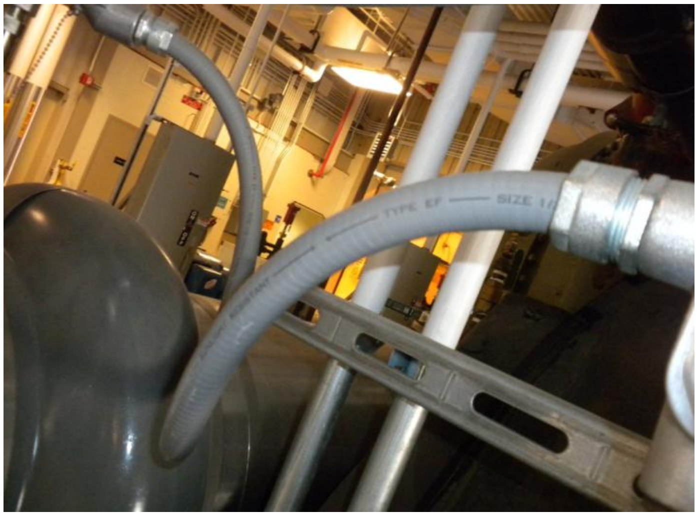

Picture A3. Working clearance observed.


Picture A4. Proper grounding of Separately Derived System.

Picture A5. Conduit compliantly supported.

B. Building 600

Building 600 was modified within the same year as this report. The team walked through the area modified and noted numerous NEC non-compliance examples, even though the Project obtained the services of an NEC inspector. Following are pictures that reflect a few of the conditions that do not comply with the NEC Code of Record.



Picture B1. Liquidtight Flexible Metal Conduit does not comply with NEC 350.6 since it is not listed by NRTL.

Picture B2. Does not comply with NEC 300.11(B) and 350.30. Raceway supporting other cables and conduit not supported within 12" of box.

Picture B3. Does not comply with NEC 314.23(F). Raceways supporting enclosure not secured within 18".

Picture B4. Does not comply with NEC 344.23(B)(1).
Rigid Metallic Raceway not supported at 10' intervals
and within 3' of an enclosure.

Picture B5. Does not comply with NEC 110.26(F)(1).
Duct within the dedicated space of switchboard.

C. Building 490

Building 490 is more than 50 years old and would not be expected to comply with current electrical installation standards. However, recent modifications made since DOE imposed consensus standards for electrical installations should be compliant. The team identified numerous examples that indicate a lack of effective NEC enforcement. The following pictures demonstrate only a few of the examples.

Picture C1. Electrical equipment not approved and does not meet requirements of 110.3(A) for suitability.

Picture C2. Does not comply with 700.12(F). Emergency unit not connected to lighting circuit ahead of switch and power cord exceeds 3' length.

Picture C3. Does not comply with 408.4.
Panel schedule not complete.

Picture C4. Does not comply with 400.8(2).
Flexible cord routed through wall.

Picture C5. Does not comply with 110.27.
Energized conductors are not adequately guarded.

Picture C6. Does not comply with 110.26(A).
New panelboard installed without working space.

Picture C7. Does not comply with 400.8(1).
The flexible cord is used as permanent wiring.

Picture C8. Does not comply with 110.3(B).
Modifications of panelboard invalidates UL

listing and leaves gaps that makes the equipment unsuitable.

Picture C9. Does not comply with 110.26(A).
Added counter encroaches on working space.

The above examples are representative of numerous non-compliance issues in facilities where installation standards are mandatory. They provide objective evidence that the NEC enforcement program has weaknesses that should be addressed, as well as evidence that a rigorous enforcement program will minimize exposure to workers and costly corrective actions.