INDEPENDENT OVERSIGHT SPECIAL REVIEW OF SAFETY AT THE NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY BOULDER LABORATORIES

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Acronyms

ACGIH	American Conference of Governmental Industrial Hygienists
ANSI	American National Standards Institute
DOE	U.S. Department of Energy
EEEL	Electronics and Electrical Engineering Laboratory
EMSS	Engineering, Maintenance and Support Services
HSI	Health and Safety Instruction
OSHA	Occupational Safety and Health Administration
NFPA	National Fire Protection Association
NIST	National Institute of Standards and Technology
PPE	Personal Protective Equipment
RCRA	Resource Conservation and Recovery Act
RF	Radio Frequency
SHED	NIST Safety, Health and Environment Division
UV	Ultraviolet

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1.0 INTRODUCTION

In response to a spill of a dispersible powder form of plutonium (i.e., plutonium sulfate tetrahydrate) at the National Institute of Standards and Technology (NIST) Boulder Laboratories on June 9, 2008, the Department of Commerce directed several investigations to examine the event and identify causes. The Deputy Secretary of Commerce determined that, in addition to these investigations, further review was necessary to provide assurance of safety and to determine whether systemic safety problems exist at the NIST Boulder Laboratories. After the Department of Commerce requested assistance from the Department of Energy (DOE), the Secretary of Energy directed the DOE Chief Health, Safety and Security Officer to support the Department of Commerce in conducting a Special Review of safety at the NIST Boulder Laboratories. The DOE Office of Independent Oversight, within the Office of Health, Safety and Security led the Special Review team, and the team also included participants from the NIST Safety, Health and Environment Division (SHED) and the NIST research divisions.

The Special Review included two onsite visits to the NIST Boulder Laboratories to observe activities, which occurred during August 4-7 and August 18-28, 2008. The review evaluated application of the NIST Safety Operational System for a sample of work activities within each Operating Unit at the Boulder Laboratories. The review was performance-based and assessed the adequacy of the system and implementation in assuring that hazards are analyzed and mitigating controls implemented to establish a safe work environment for each activity, consistent with requirements established in Federal, state, and local regulations and in NIST internal policies and requirements.

The scope of the review included technical program and site infrastructure activities conducted at the NIST Boulder Laboratories. Hazards at the NIST Boulder Laboratories include ionizing and non-ionizing radiation, hazardous chemicals, and various physical and electrical hazards associated with research activities, facility operations, maintenance, and construction. The Special Review team reviewed selected ongoing research activities within various Operating Units, including Electronics and Electrical Engineering, Chemical Science and Technology, Physics, Materials Science and Engineering Laboratories, and within the Engineering, Maintenance and Support Services (EMSS) Division. The review also included sampling of maintenance and construction activities performed within the EMSS Division. The work activities to be reviewed were selected based on the degree of risk they present. Observations and discussions with responsible staff were conducted to determine whether appropriate controls have been established to protect workers from the hazards present.

Sections 2 and 3 discuss the key positive attributes and weaknesses, respectively, identified during this Special Review. Section 4 provides a summary assessment of the effectiveness of the major safety elements that were reviewed. Section 5 provides Independent Oversight's conclusions regarding safety at the NIST Boulder Laboratory. Appendix A provides a set of opportunities for improvement for consideration by NIST management and the Department of Commerce, and Appendix B provides supplemental information, including team composition.

2.0 POSITIVE ATTRIBUTES

The NIST management and staff have been proactive in responding to the safety deficiencies identified during the Special Review. Where feasible, NIST management has established near-term actions or compensatory measures to address many of the observed examples of safety deficiencies. For example, more fencing and better controls for vehicular traffic have been put in place to control access to active construction areas more effectively. Within laboratories, oxygen deficiency calculations were performed, and a contractor was sought to test laboratory chemical hoods. The electrical work of two contractors was stopped, pending the implementation of EMSS-approved corrective actions; one of these two contractors is now in compliance and has resumed work. EMSS has ordered standardized lockout/tagout devices, and a new lockout/tagout procedure has been developed and is being implemented. NIST management and staff were actively engaged in the Special Review activities and used the process as a learning opportunity.

Research scientists are knowledgeable within their areas of expertise and, in many cases, have established appropriate controls for hazards within their areas of expertise. Research scientists also contribute to the training and education of others within their own and other divisions. For example, cryogen experts have developed cryogen training, and laser safety subject matter experts have developed and provided laser safety training. However, as discussed throughout this report, safety management relies too much on individual expertise at the working level, and many hazards were not identified and controlled.

In response to the plutonium incident, a sitewide effort has been initiated to identify and eliminate excess and unnecessary chemical inventory. Ongoing actions were evident throughout NIST Boulder Laboratories. This effort, if completed effectively, should significantly reduce the risks from legacy chemicals.

3.0 WEAKNESSES

The following weaknesses contributed to numerous unsafe conditions and/or unanalyzed hazards observed by the Special Review team.

NIST management has not established a safety management system and accompanying protocols. The current process relies too much on individuals who may not have the requisite knowledge for identifying all hazards and ensuring that appropriate controls are established. NIST has issued a number of institutional safety and health program and protocols, such as the Safety Operational System, the Laboratory Safety Manual, and Health and Safety Instructions (HSIs). However, management has not communicated expectations for implementing these programs and protocols, and they have not been widely used. In most cases, line management and staff at Boulder Laboratories were not involved in developing the NIST safety programs and protocols and are generally unfamiliar with them and uncertain about their application to ongoing research. In some cases, they are perceived as non-mandatory guidance. Additionally, many of these documents have not been maintained or kept current, and NIST divisions have developed ad hoc requirements and documents. NIST staff indicated that they are reluctant to use some of the institutional documents because they may be out of date. Many elements of the NIST Safety Operational System, Laboratory Safety Manual, and HSIs have not been implemented or followed, contributing to observed unsafe or unanalyzed conditions. In addition, some applicable requirements and standards contained in Occupational Safety and Health Administration (OSHA) regulations and industry standards, such as those issued by the American Conference of Governmental

Industrial Hygienists (ACGIH), the National Fire Protection Association (NFPA), and the American National Standards Institute (ANSI), were not identified, addressed in institutional safety and health protocols, or communicated to the researchers, resulting in many instances of non-compliance with those standards.

Safety roles and responsibilities are not clearly defined. This situation contributed to several observations, such as researchers performing building modifications, including wall penetrations and routing electrical wiring, without the requisite safety controls. Researchers, as well as maintenance and construction staff members, indicated a reluctance to seek the help of the Boulder Laboratories safety staff in resolving issues. Most laboratory chemical hoods have not been tested to verify their continued operability and ensure protection of the workforce for more than five years, because responsibilities for performing these tests were not understood. The combination of a lack of mutual respect and confidence between research organizations, SHED, and EMSS, along with insufficient definition of roles, responsibilities, and authorities hinders effective safety management.

Systematic processes for managing requirements, analyzing hazards, mitigating risks, and specifying controls are inadequate or non-existent. A fundamental aspect of safety management is that requirements are identified and standards are agreed to, at the institutional level, before work is authorized. In addition, processes are needed to ensure that for each activity to be performed, hazards are identified and analyzed, and applicable controls are applied to mitigate these hazards. The NIST Laboratory Safety Manual and HSIs identify requirements for many hazards present at the Boulder Laboratories, but in many cases the applicable requirements and standards were not applied to mitigate hazards before activities were performed. There is no effective process for ensuring that safety and health requirements are established at the institution level and that these requirements are accurately communicated to NIST personnel through organizational implementing procedures. In some cases, external requirements are not properly identified or correctly reflected in organizational practices. Additionally, authorities having jurisdiction, as defined in NFPA 1, have not been established for identifying and enforcing applicable standards for such areas as electrical safety and fire protection.

NIST Boulder Laboratories does not have sufficient subject matter expertise assigned to the Office of Safety, Health and Environment in a number of important safety areas. The Special Review team identified numerous examples where exposures to hazardous materials, non-ionizing radiation, fire hazards, and noise were not adequately analyzed, understood, or controlled, and the NIST Boulder Laboratories safety staff does not have the expertise to perform these analyses effectively. For example, there is no certified safety professional, certified industrial hygienist, or fire protection engineer on the NIST Boulder Laboratories staff. NIST management is aware of the need to add safety expertise to the Boulder Laboratories staff and is taking steps to address this need.

Worker training is not methodical and is inconsistent among groups. Mechanisms have not been adequately established to define training requirements for hazards to which workers are exposed. Each group establishes training requirements based on professional judgment, and there are very few institutional training courses. In general, line managers identify a resident expert who informally provides training/mentoring of others in the group, if requested. Line managers use the NIST Occupational Health and Safety Orientation checklist (NIST-1197 form) to define training requirements for their employees, but the form has a number of deficiencies. For example, it does not address some significant hazards, such as magnetic fields, cryogens, lasers, confined space entries, and electrical safety, although some research Operating Units augment the form on an ad hoc basis to identify unique hazards. More importantly, in most cases the form is completed only at the time of employment and is not revisited again, even though the employee’s job tasks and hazards may change considerably over the period of employment.

Facility conditions in most of the NIST buildings are not conducive to conducting research safely. Much of the research at NIST is performed in buildings or laboratories that do not meet current building codes and standards, are in deteriorating condition, or do not support the research that is conducted within the facilities. For example, most of the research laboratories in NIST Building 1, and several in Building 2, do not have a fresh air supply; the research staff relies on re-circulated air or air from the corridors. When laboratory doors are closed, hazardous fumes or airborne metals or dusts are likely to remain in the breathing spaces or dissipate slowly. Numerous laboratory chemical hoods and eyewash stations are in use throughout the NIST laboratories, but few have been tested on a routine basis in recent years in accordance with industry standards (i.e., ANSI standards), and there is no assurance that the hoods and eyewash stations provide the required level of worker protection. Many laboratories do not have the capability to install local ventilation systems when needed to reduce the risk of worker exposure to toxic fumes and vapors. Compressed air supply systems have not been tested in recent years and may be contaminated with various oils and greases. Roofing leaks are routine, and potential mold issues were observed in some laboratories. Some research work is conducted in temporary facilities that have long exceeded their design life. In one building, floor-mounted high voltage power sources for lasers are positioned on temporary construction lumber (i.e., 2"x 4" studs) due to the potential electrocution hazard during heavy rains, when the basement floods up to a depth of two inches. Roof leakage and pipe breaks have resulted in comparable safety hazards in other laboratories and buildings. Housekeeping in many of the facilities is poor, as indicated by excessive combustibles and potential fire hazards and blocked access to electrical panels, fire extinguishers, showers, and eyewash stations.

NIST has not established effective mechanisms for ensuring that maintenance and construction contractors meet applicable safety requirements. Contracts do not adequately identify applicable requirements and do not provide incentives for good performance or penalties for poor performance. NIST has not required construction contractors to establish processes for systematically and frequently analyzing hazards and reminding workers of these hazards and the applicable or needed controls. The NIST programs for reviewing contractor safety plans and for overseeing contractor safety performance have not been formally established or consistently implemented. NIST management understands the need to strengthen programs and processes for managing maintenance and construction safety and has initiated actions to improve performance in these areas, but has not developed plans with deliverables, milestones, and schedules.

NIST and the Department of Commerce have not established effective continuous improvement processes to support continuous safety improvement. A key element of a safety management system is that it provides a mechanism for assessing performance and managing corrective actions to resolve deficiencies and prevent recurrence. Although NIST personnel have conducted walkthroughs of facility areas and have identified and corrected specific deficient conditions, there is no NIST-wide, documented process for identifying and correcting systemic problems to prevent recurrence.

4.0 RESULTS

The following sections provide a summary assessment of the conditions and activities at NIST Boulder Laboratories that the Special Review team evaluated during this inspection.

4.1 Research

The Special Review team reviewed selected ongoing research activities within various Operating Units, including Electronics and Electrical Engineering, Chemical Science and Technology, Physics, and Materials Science and Engineering Laboratories. Although many research activities are managed adequately, the Special Review team observed numerous unsafe conditions and/or unanalyzed hazards throughout all divisions that present an increased risk to worker safety and health. The following paragraphs further describe topical areas of concern that cut across all divisions.

4.1.1 Hazardous Materials

Chemicals are used extensively at NIST Boulder Laboratories for various research activities. In many cases, researchers handle chemicals safely, and in some cases, facility design further supports safe handling. For example, the Division Safety Representative is actively involved in the mentoring, training, and qualification of Quantum Fabrication Facility (Clean Room) workers, and workers are knowledgeable about the hazards. In addition, the design of the Clean Room appropriately considered fire protection, ventilation, toxic gas minimization, effluents, and alarm systems.

However, deficiencies in procurement, storage, use, and disposal of hazardous materials present several vulnerabilities that could negatively impact workers or the environment. In several instances, NIST does not meet OSHA and Resource Conservation and Recovery Act (RCRA) regulations and/or several commonly accepted industry standards, including NFPA and ANSI standards.

Material Procurement

There are no NIST requirements for safety or hazard reviews associated with chemical procurements, contrary to the requirements of ANSI Z10, *Occupational Health and Safety Management Systems*. With a supervisor’s concurrence, researchers may purchase or otherwise obtain hazardous chemicals directly from any source, such as vendors, the Internet, other government agencies, research collaborators, or existing NIST inventory. Divisions conduct an annual chemical inventory that depends on the research staff to update the chemical inventory database, but the accuracy of the database is not periodically verified in the field. In several research groups, the current chemical inventory did not list a number of chemicals that were present in the laboratories. In addition, the inventory also listed a number of carcinogens for which the hazard controls specified in the HSIs had not been implemented.

Material Storage

Deficiencies in storage of chemicals included numerous instances of chemicals (including compressed gas cylinders) that were not properly stored in accordance with minimum safety requirements established by OSHA and current NFPA standards. As examples:

- Many compressed gas cylinders were improperly stored inside flammable-liquid storage cabinets (e.g., collocated with flammable liquids), were not secured with chains or strapping, or were lying on their sides.
- Some cabinets containing hazardous chemicals and compressed gases were not marked to indicate the hazards, contents, dates, or contact/owner information.
- Many chemical storage cabinets and other storage areas contained incompatible chemicals stored together, and some individual chemical containers were not labeled with contents or hazards.
- Flammable liquids were not labeled to identify the flammability hazard in some cases.
- Aqueous solutions in glass containers were stored in outdoor cabinets without any apparent consideration of the effects of freezing.
- Chemicals with labels specifying controlled environments were stored in outdoor storage cabinets.
- In many instances, flammable liquids were improperly stored (e.g., gallons of flammable liquids stored on floors or carts, or in cabinets underneath sinks).

In one case, several chemical storage cabinets (including two unmarked and padlocked general use storage cabinets) were located on a covered outdoor dock, intermingled with flammable liquid storage cabinets in a compressed gas cylinder storage area. These chemical storage cabinets contained numerous toxic chemicals, carcinogens, incompatible chemicals (strong acids, bases, and oxidizers), and containers labeled as biohazards, with evidence of previous leaking containers. There were over twice as many flammable storage cabinets in this area as NFPA standards allow for fire loading, thereby potentially exceeding the fire loading design of the installed sprinkler system. The combination of cabinets containing numerous hazardous and incompatible materials with flammable liquids and flammable compressed gas cylinders provides a significant risk of release of hazardous chemicals, toxins, and carcinogens to the environment and surrounding community in the event of a fire or spill.

Material Use

Cryogens are in use in many research laboratories. Although many of the researchers are knowledgeable of cryogen hazards and controls, the team observed several cases where institutional training or guidance had not been provided in the safe use of cryogens. In most of the laboratories that were reviewed, no consideration had been given to the potential for creating oxygen-deficient atmospheres in the event of a rupture of cryogen storage tanks or during other evolutions where rates of vaporization of cryogens are high, such as filling multiple warm dewars. During the review, NIST performed oxygen deficiency calculations for several of the research laboratories with this potential risk and initiated installation of oxygen monitors where indicated.

Some chemical use practices during research do not meet minimum OSHA and RCRA regulations or commonly accepted industry standards. Hazard controls are generally the responsibility of the individual researchers and are not based on an activity-level hazard analysis and comparison to minimum safety requirements. As examples:

- Solder containing lead is routinely used throughout the NIST laboratories. However, workers have not been trained regarding lead hazards, and most are unaware of the potential hazards of lead fumes. Exposure assessments have not been performed, no monitoring of surfaces for contamination has been conducted, the need for local ventilation has not been evaluated, no controls or expectations are in place for housekeeping matters in activities using lead, and no means for capturing the hazardous waste generated from soldering and brazing have been established. Researchers were not aware that the lead solder waste was hazardous, and they routinely disposed of it in the sanitary waste.
- Similar conditions existed for other hazardous materials, such as beryllium fines produced during drilling of copper-beryllium alloys. Beryllium is a particular concern because of the potential for beryllium-sensitized individuals in the NIST Boulder Laboratories workforce. In another example, some laboratories use methylene chloride but have not established controls consistent with OSHA requirements for working with methylene chloride, such as exposure monitoring, training, and appropriate personal protective equipment (PPE).
- Most of the NIST research staff, workers, and line managers are not aware of the OSHA medical surveillance requirements and/or NIST medical programs available for noise, exposure to certain hazardous chemicals (e.g., beryllium, lead and other heavy metals, methylene chloride, asbestos), and the use of air purifying and face filtering respirators.
- In a number of activities where hazardous chemicals, such as dry or dispersible nanomaterials, solvents, and specialty adhesives, are handled outside of engineering containment controls (e.g., laboratory chemical hoods), the potential for exposure has not been assessed. A specific example of this potential is spray application of carbon nanotubes (suspended in solution) onto substrate samples, performed inside a cardboard box to capture overspray. This activity was conducted in a laminar flow hood, which is not adequate for painting because the flow paths could cause currents and allow materials to escape. No exposure monitoring or hazard assessment had been performed to ensure that the established controls were adequate to protect the workers.

Although OSHA regulations require hazard assessments to determine appropriate PPE when there is a potential for exposure to hazardous materials, PPE selection is often left to the judgment of the individual. For example, latex, nitrile, and other chemical protective gloves and equipment are available for use, but documented hazard assessments correlating the type of glove to use with the various hazardous chemicals have not been performed in most cases, as required by OSHA 1910.132. There are similar concerns about PPE for thermal protection during cryogenic liquid use and transfer.

Material Disposal

In many cases, researchers are not familiar with and do not follow hazardous waste regulation requirements. In addition to the improper disposal of the lead solder hazardous waste discussed above, the Special Review team observed many waste accumulation areas within research areas where the waste containers were not labeled to accurately identify the contents. Some wastes generated in laboratories present unique hazards to waste handlers, but these hazards have not been communicated so that compensatory measures can be implemented. For example, waste handlers were not initially informed of waste mixtures of acids and alcohols that could react to form potentially explosive compounds, and a waste solution that could react violently with organics (and also overpressurize the container from off-gassing) was collected in a container that the generator believed to be incompatible with the waste solution during long-term storage (greater than 90 days). These situations present both a direct hazard in handling and storing the wastes, and an increased potential for creating additional hazards from combining wastes prior to disposal.

In the central waste accumulation and storage area, wastes are handled and stored in three separate rooms. However, only one of these rooms contains an emergency shower and eyewash station, which has not been recently inspected or maintained and is not adequately accessible from the waste bulking room. The storage area is ventilated and designed with explosion-proof fixtures but cannot operate as an explosion-proof area because non-explosion-proof equipment, such as a refrigerator rated for flammable storage and a vacuum cleaner, is being used. Although waste hydrofluoric acid is handled in the facility, calcium gluconate, used for initial treatment in case of contact, is not available in the facility. Most waste containers are not individually labeled in accordance with regulatory requirements, and information provided by generators is not sufficient to prevent incompatible materials from being bulked by either NIST or contractor employees. Numerous waste containers are improperly marked, and many containers are in either original stock solution containers or reused bottles, without re-marking or appropriate labeling. This situation was the basis for several inspection findings issued by the Colorado Department of Public Health and Environment in 1997 and 2003. In addition, some waste containers are emptied and provided back to laboratories for reuse; there is no indication that these containers are rinsed in the interim, creating a potential for interactions between residual contents and newly added wastes.

4.1.2 Non-ionizing Radiation

A number of environment, safety, and health vulnerabilities associated with non-ionizing radiation (i.e., radio frequency, microwave, and static magnetic fields and lasers) were observed at NIST Boulder Laboratories research laboratories and radio station operations.

Magnetic Fields

Potential worker exposures to magnetic fields have not been evaluated and/or documented for a number of research projects that utilize moderate to high intensity magnets for research applications. Examples include workers being in close proximity (within 24 inches) of a 4.5 tesla (T) magnet for prolonged durations, with no measurement or marking of field strength and no assurance that actual exposures do not exceed industry standards, such as the ACGIH ceiling limit of 2 T to the whole body. Several other activities use similar magnets in laboratories; these have warnings posted on doors but have no health-related basis for the warnings or definitive boundaries for the areas. Additionally, a number of laboratories with magnetic fields have no hazard warning posted on the laboratory door to warn entering individuals, including those with pacemakers for whom exposures greater than 5 Gauss may be an imminent health risk. In several cases, temporary postings (e.g., taped to the side of the equipment) are used to indicate the presence of magnetic fields, but they do not provide workers with information about the field strength or safety precautions. In one case, a hazard review conducted for a specific equipment application indicated that "magnetic fields will be monitored with a gauss meter as part of scheduled maintenance." However, this routine monitoring is not performed. NIST Boulder Laboratories has no requirement to measure magnetic fields and determine the magnitude of the magnetic field hazard, and NIST has not established requirements or training programs for working with magnetic fields.

Radio Frequency and Microwave Fields

Numerous research projects involve the use of radio frequency (RF) generators and microwaves, and NIST also maintains radio transmission facilities (WWVB) at Wellington, Colorado. While most RF and microwave experiments have low hazard potential, a few research projects may have higher potential hazards. Typically, field strengths are not measured and documented to ensure that workers are not exposed to RF and microwave signals that may result in potential health effects. At the NIST radio transmission facilities, both low and high frequency signals are generated, in addition to other communication modes. With the assistance of the U.S. Navy, the transmitters at the facility underwent a major upgrade in 1999 to increase output. At that time, the NIST staff believes that the Navy conducted some modeling of potential RF fields, but no measurements have been conducted. NIST workers at the Wellington site have requested measurements through their management and the NIST Office of Safety, Health and Environment in the past; however, no actual measurement of RF fields or assessment of potential occupational exposures to RF have been conducted for workers at this site or at the property fence line. Potential exposures are in the range of 2.5 to 30 MHz; ACGIH has established threshold limit values (milliwatt/cm^2) to limit worker exposures for this range.

Lasers

Hazards are not always adequately analyzed and/or documented, and in some cases controls are not sufficient for working with lasers. The NIST requirements related to safety for laser operations across NIST Boulder Laboratories are contained in HSI 13, *Laser Safety*. However, this document is outdated (1996), and ANSI Z136.1, *Safe Use of Lasers*, has been revised twice since then. Researchers identify these document deficiencies as the basis for not using the HSI, and a revision is in process. However, because the NIST system does not allow the HSIs to be updated easily, many divisions have adopted ad hoc policies. For example, the Electronics and Electrical Engineering Laboratory (EEEL) has developed a Laser Safety Policy (developed in 2002 and revised several times, most recently on 11/27/07). The policy requires all lasers and laser systems to be operated in a manner consistent with ANSI Z136.1 and other applicable regulations, and EEEL has provided training to users throughout the NIST Boulder staff. The referenced source requirements are complex and require engineering controls, administrative controls, and training. The goal of the EEEL policy is to inform laser operators of potential laser hazards and educate them so that potential injuries are avoided. The policy has been used by other divisions within Boulder Laboratories and is being considered for wider adoption throughout NIST.

Although researchers are extremely knowledgeable of the use of lasers and applicable properties as applied to their research, some vulnerabilities were observed. Both ANSI Z136.1 and the NIST Laser Safety HSI specify that engineering controls should be applied to ensure laser safety where practical, and laser safety practices at NIST Boulder Laboratories rely largely on the EEEL policy, which is a hybrid of engineering and administrative controls and PPE. However, in some cases, the Special Review team observed administrative controls that were improperly implemented or that were not as effective as equivalent engineering controls. For example, postings and warning lights for administrative control of laser hazards are either not followed as specified or not understood by many workers. Some individuals entered laboratories when red lights were illuminated without seeking prior authorization from the occupants to confirm that the specified controls, such as curtains, were in place. In some laboratories where lasers were in use, the warning lights were not illuminated; in some laboratories where warning lights were illuminated, no lasers were in use. Safety controls for an ultraviolet (UV) laser hazard in one laboratory consisted primarily of administrative controls and PPE (UV safety glasses). However, one of the two individuals conducting alignment and equipment setup was not wearing appropriate clothing to protect against inadvertent dermal exposure (potential skin cancer risk). In one laboratory, a protective cover on a carbon dioxide (CO_2) laser had been removed during alignment and was not replaced when the laser was returned to operation. In another laboratory, one laser table optics assembly was at eye level but had no engineering controls to protect against potential eye damage. Lastly, although the ANSI standard discusses the need to control specular reflectors to protect individuals against reflected emissions and most researchers are aware of these considerations, some researchers wore jewelry, such as rings, watches, and bracelets.

4.1.3 Physical Hazards

Each of the observed research divisions conducts activities involving one or more physical hazards, such as those related to electrical safety, confined spaces, elevated work, material handling, and facility conditions. For these hazards, NIST has insufficient policies, procedures, hazard analyses, and hazard controls to ensure that the research staff conducts work safely.

Electrical Safety

The Special Review team observed a wide range of electrical hazards associated with research apparatus in which the research staff performs repair, servicing, and maintenance based on their knowledge and experience, but without a lockout/tagout procedure and employee electrical safety training as required by the NIST HSI 21, *Control of Hazardous Energy*, and OSHA electrical standards. In addition, many laboratories have blocked electrical panels, researchers extensively rely on daisy-chained extension cords, and combustibles are in the vicinity of electrical sources, all contrary to industry good practices and/or OSHA regulations. Since many workers are unfamiliar with the NIST and OSHA PPE requirements for working with hazardous energy, electrical safety practices used by workers within a research division may not meet NIST requirements. This situation is a particular concern for such tasks as performing zero energy checks, where the only PPE used by some electricians is safety glasses and voltage rated gloves. In some cases, facility staff members, including the electricians, were unaware of the hazards associated with arc flash (including NFPA 70E) and/or requisite PPE for protecting workers from arc flashes.

Confined Spaces

Confined spaces in the floors of some laboratories and in large research apparatus were not posted or documented. These spaces are, or may be, entered on a periodic basis by the research staff. In all cases, the research staff members were unaware of the potential hazards of these spaces, the spaces had not been analyzed for potential hazards, and the staff could enter these spaces without the training, monitoring, and administrative controls required by OSHA.

Elevated Work

At several research locations, the research staff work at elevated heights without appropriate fall protection, and they use ladders or construct scaffolding without any training or hazard recognition as required by OSHA and/or general industry practices. In one example, a researcher used a body belt for fall protection; NIOSH safety bulletins discourage using body belts rather than harnesses because it may increase injuries to the worker. In another example, the main radio station building has no fall protection (e.g., guard railing, parapet), and workers who access the roof (which is slightly pitched) to work on equipment stated that they use no PPE but try to stay away from the edge. The fall protection equipment for three individuals who climb the eight radio towers for maintenance is not maintained in any type of inventory/inspection system (e.g., a log to ensure that inspections are conducted before use and/or at the frequency required by the manufacturer). In some cases, researchers conduct hoisting and rigging operations without adequate training, lift plans, or documentation of strapping inspections.

Material Handling

Researchers operate fork trucks and material handing devices without current training, and they do not conduct safety inspections as required by OSHA. For example, a researcher who routinely operates a fork truck had not received fork truck training since the early 1980s, even though the OSHA standards have changed since the early 1980s and refresher training is required every three years.

Machine Shops

Each of the NIST research divisions operates one or more machine shops or laboratories in which hazards are not well understood and hazard controls have not been adequately identified, designed, and/or implemented. Although machining of hazardous and toxic materials is or could be conducted in some of these machine shops, the potential for inhalation of hazardous or toxic materials (e.g., beryllium copper, aluminum, nickel) has not been evaluated, and the researcher is responsible for identifying and implementing controls (e.g., local ventilation, respirators). Poor housekeeping practices in many areas (i.e., accumulation of machining dust and fines on benches and machine tools) and the machining of these materials in laboratories that have no fresh air supply ventilation exacerbate the health risks. Health risks resulting from exposure to some of these hazardous materials, such as could occur when machining beryllium-copper alloys, are not well understood by or communicated to the staff. A number of these machines (e.g., drills, lathes, grinders, and break and shear presses) are old and do not have adequate machine guarding, emergency stops, or anchorage, as required by OSHA. Also, some of these machines produce high noise levels that have not been evaluated, and it is not known whether hearing protection should be worn or whether researchers should be entered into the hearing conservation program as required by the NIST Hearing Conservation Program and OSHA regulations.

Material Testing

Some activities involve the use of mechanical equipment to stress metals or other materials to failure. The Laboratory Safety Manual does not include requirements for operating this type of equipment, although a section is reserved for such requirements. The operators recognize the hazardous nature of these tests and take steps to minimize some of the hazards, but in some cases these controls are not documented. Additional hazards may be present that have not been identified by the operators. For example, some impact testers have an increased potential for snagging loose clothing or lanyards during operation, and the potential for failure of catch pins due to wear has not been evaluated or considered. In addition, there is a reliance on administrative controls when engineering controls could be more effective.

Facility Conditions

Facility conditions in most of the NIST buildings are not conducive to conducting research safely. Most of the research laboratories in NIST Building 1, and several in Building 2, do not have fresh air; the research staff relies on re-circulated air or air from the corridors. When laboratory doors are closed, hazardous fumes or airborne metals or dusts are likely to remain in the breathing spaces or dissipate slowly. Numerous laboratory chemical hoods are in use throughout NIST Boulder Laboratories, but few have been tested in recent years to evaluate whether air face velocities are adequate, and a number of these hoods are not operated in accordance with industry standards. In many cases, hazardous chemical activities that produce fumes or vapors are conducted in laboratory chemical hoods, but there is no assurance that the hoods provide the expected level of worker protection. In one instance, a gas that can react with water vapor to form an explosive solid was vented in a hood without evaluation of the potential for this solid to accumulate within the ventilation system. Most eyewash stations are not routinely tested as specified by ANSI Z 358.1 to ensure that they will function as required, and eyewash bottles may be outdated and are sometimes improperly staged as permanent equipment, contrary to the guidance in the ANSI standard. Roles and responsibilities for the testing and maintenance of laboratory chemical hoods and eyewash stations are not defined. In some facilities, biological hazards (rodent droppings) were evident, but there is no protocol for protecting workers from rodent-related health effects, such as hantavirus. Workers stated that they spray droppings with dilute bleach prior to cleanup. In one building, floor-mounted high voltage power sources for lasers are positioned on temporary construction lumber (i.e., 2" x 4" studs) due to the potential electrocution hazard during heavy rains, when the basement floods up to a depth of two inches. Roof leakage and pipe breaks have resulted in comparable safety hazards in other laboratories and buildings. Housekeeping in many of the facilities is poor, as indicated by excessive combustibles and potential fire hazards and blocked access to electrical panels, fire extinguishers, showers, and eyewash stations.

In some cases, the research staff performs maintenance-like facility work without conducting hazard reviews or ensuring that the appropriate hazard controls are in place. For example, work performed during maintenance of an antenna laboratory resulted in the creation of dust, which had not been previously analyzed for potential worker exposure. Although the research staff performing the work donned dust masks, there was no exposure assessment to quantify the magnitude of the dust hazard or the adequacy of the dust mask for these exposure conditions, and the workers were not enrolled in the NIST respiratory protection program.

4.2 Maintenance

EMSS for NIST, within the Chief, Facility and Maintenance Officer organization in Gaithersburg, Maryland, is responsible for designing, constructing, operating, and maintaining NIST facilities and infrastructure. Contractors under the direction and oversight of EMSS perform a variety of maintenance and repair activities. The Special Review team evaluated the EMSS work planning and control and hazard identification and control processes and observed a variety of maintenance work, such as electrical work, equipment repair and maintenance, materials handling, janitorial work, and craft work conducted by NIST employees and contractors in various buildings, maintenance shops, and equipment rooms.

4.2.1 Hazard Identification and Control

A number of hazards associated with maintenance activities have not been adequately analyzed or controlled. This situation was particularly evident for electrical work, where controls were not adequate to protect workers from electric shock or arc flash hazards. For example, workers at some job sites did not wear required PPE, electrical equipment was not properly de-energized and verified as de-energized (i.e., locked-out/tagged-out), and ground fault current interrupters (GFCIs) were not used with noninsulated electrically powered hand tools. Only two of the six observed electrical equipment lockout/tagouts conducted by contractors/NIST employees were accomplished in accordance with applicable procedures, exposing the workers to significant risk from electrical shock and arc flash burns. Inadequate training contributed to these deficiencies. Most of the EMSS craftsman attended lockout/tagout training during January 2008, but EMSS does not have a lockout/tagout procedure (as required by HSI 21, *Control of Hazardous Energy)*, and standardized lockout/tagout devices were not used. Arc-flash protective clothing was issued to NIST electricians, but the requirements for its use were not proceduralized and training was not conducted. Voltage-rated electrical protective gloves have not been tested as required by OSHA, and test and issue procedures have not been implemented. Contractor employees have not been adequately trained on their respective companies' lockout/tagout procedures.

The Special Review team observed numerous other examples of inadequate hazard identification, analysis, and control. Machine tools in several areas are improperly anchored and improperly guarded, and woodworking machinery has inadequate belt/pulley guards and inadequate or missing "point-of-operation" guards. Hazards associated with removal of sanitary waste, which may contain broken glass or other sharp objects, chemicals, or toxic metals, have not been fully analyzed. Potential exposures of workers on roofs to the exhaust from laboratory chemical hoods have not been analyzed. Forklift operators have not received the requisite tri-annual training. Eyewash fountains and showers in maintenance shops and equipment rooms are in disrepair and have not been maintained to meet OSHA requirements. Maintenance workers are routinely exposed to noise sources so loud in some cases that normal speech is difficult to understand, but they have not been enrolled in a hearing conservation program, and noise exposure monitoring has not been conducted as required by HSI 8, *Hearing Conservation.* Most of the noisy areas are not adequately posted as requiring hearing protection.

The Special Review team reviewed the NIST asbestos program as described in HSI 18, *Asbestos-Containing Material*. EMSS craftsmen and supervisors receive annual asbestos awareness training, and the EMSS subject matter expert for asbestos receives annual *Supervisors Asbestos Hazard Emergency Response Act - Environmental Protection Act (AHERA-EPA)* training. EMSS maintains a database showing the specific locations of asbestos-containing material, but EMSS craftsmen and contractors are not routinely provided with information from the database prior to commencing work. Laboratory personnel, who are not generally aware of the database or asbestos control requirements, routinely drill holes in walls and ceilings, thereby risking potential exposure to asbestos-containing materials.

4.2.2 Work Planning and Control

The NIST work planning and control process is not established through procedures and relies on "skill-of-the-worker" for hazard recognition, analysis, and control. EMSS has not implemented a job hazard analysis program to determine the hazards associated with work assignments, identify the training required by the craft to safely accomplish assigned work, determine appropriate PPE requirements, and determine the scope of work that can be completed by individual craft skill categories considered "skill-of-the-worker." EMSS does not routinely solicit safety subject matter expertise to assist in hazard identification and control, and EMSS management stated that the response to requests, when made, is inadequate. EMSS has not established a process or procedure for reviewing contractor health and safety plans or preventive maintenance procedures that are included in maintenance contracts, and these plans and procedures do not always adequately address hazards that may be encountered at NIST Boulder Laboratories. In addition, implementing procedures have not been established as required by HSIs in a number of safety areas, such as electrical safety, hearing conservation, and PPE. Consequently, workers are subjected to increased risks because of inadequate hazard identification and training and, in some cases, inadequate PPE. Further, EMSS roles and responsibilities are not clearly defined within NIST; other organizations routinely perform unauthorized work on facilities and systems that are under the cognizance of EMSS. Interface protocols for work scheduling and information exchange between EMSS and other NIST organizations are poorly defined or nonexistent. EMSS considers the subject matter expertise support available within NIST to be generally inadequate and in some cases non-responsive for hazard identification, analysis, and control.

4.2.3 Feedback and Improvement

Feedback and improvement processes have not been fully implemented for maintenance activities, as the Special Review team confirmed by discussions with workers and attendance at daily pre-job meetings and management staff meetings. Because work audits and self-assessments are not conducted and feedback from workers is not formally solicited and captured, feedback is not captured for continuous improvement.

Although specific deficiencies were promptly corrected, much work remains to be done to prevent recurrence of these and similar deficiencies. On a positive note, EMSS management demonstrated a high regard for employee safety, and most employees demonstrated their intent to work safely.

4.3 Construction

Significant construction is under way at NIST Boulder Laboratories. Steam, chilled water, and compressed air facilities are being consolidated in a new Central Utilities Building, and underground distribution systems are being installed for these utilities. Roads, parking lots, exterior lighting, and storm water systems are being reconfigured. Hazards associated with this work include those associated with use of heavy construction equipment, excavations, and confined space entries.

Contractors perform construction under the direction and oversight of the EMSS Division. EMSS works with the NIST procurement staff to include applicable safety requirements in the contracts and provides daily oversight to monitor compliance with these requirements. The Special Review team observed construction activities, reviewed records, and discussed programs and practices with contractor and NIST representatives.

4.3.1 Work Practices

The Special Review team identified a number of unsafe and non-compliant work practices. Excavations were not properly barricaded, access to construction areas was not adequately controlled, permits were not issued when required for hot work and confined space entries, buried utilities were struck during excavations, and appropriate PPE was not always worn. Some of these deficiencies were significant safety vulnerabilities. For example:

- Some individuals who were not construction workers and were not wearing appropriate PPE regularly entered construction areas, where they were at risk of being struck by heavy construction equipment.
- A contractor employee who had not been trained for confined space entry was assigned to enter a permit-required confined space. No permit had been completed for this entry.
- A buried electrical conduit was struck by excavating equipment. In this instance, the conduit was deformed but not broken, and no injury resulted.

Many of the identified deficiencies resulted from contractor employees' failure to comply with established requirements that they knew, or should have known, were applicable. Examples include the failure to barricade open excavations as required by OSHA and the failure to wear required PPE. Other deficiencies occurred because requirements and expectations were not clearly established. Examples include a contractor that was not aware of NFPA 241 fire protection requirements for construction. Several deficiencies can be attributed to a lack of formal NIST programs, processes, and procedures.

Examples include a lack of procedures (or other controls) that require hand digging in the vicinity of buried utilities, and the lack of a process for identifying industry standards that are adopted by NIST. The access control deficiencies can be largely attributed to a willingness to accommodate line managers not wanting to inconvenience their employees or not enforcing established controls.

4.3.2 Contract and Requirements Management

In the area of contract management, NIST has not used incentives to encourage construction contractors to improve their safety performance. EMSS has identified repetitive compliance and safety deficiencies, indicating that contractor corrective actions have not been effective in preventing recurrence, and contractor safety performance is not improving. Contractors are not rewarded when they work safely and are not penalized when they do not; thus, they have little incentive to improve their performance. NIST is aware of this problem and is considering actions to address it.

In the area of requirements management, NIST does not have a process for identifying applicable requirements or flowing them down through the organization to the individuals who are responsible for implementing them. For example, construction contracts require compliance with all of the more than 200 NFPA standards and specifically list a few of these standards, but in practice, compliance with these standards is not enforced. Similarly, contracts require compliance with "all applicable site safety and health requirements." However, they do not effectively convey NIST expectations because they do not specify which of the site requirements are applicable. The minutes of pre-construction meetings, which are conducted to convey NIST expectations for contractor performance, indicate that there has been little discussion of applicable safety requirements at these meetings.

In the area of hazard analysis and control, NIST has not required construction contractors to establish processes for systematically and frequently analyzing hazards and reminding workers of these hazards and the applicable or needed controls. The Special Review team identified hazards that had not been identified and workers who were not aware of applicable controls. Contractors discuss safety topics with their employees during weekly safety meetings, but they do not systematically analyze hazards or remind workers of the hazards and controls associated with assigned tasks on regular basis.

4.3.3 Feedback and Improvement

NIST has not established fully effective feedback and improvement processes for construction safety. NIST oversight inspections of construction work have identified numerous safety deficiencies, but the results of these inspections have not been consistently documented, and thus have not been used effectively to support management decisions in such areas as program improvement and contract management. Further, a post-job review process has not been established to assess contractor safety performance upon completion of construction projects.

5.0 CONCLUSIONS

NIST senior management and Boulder Laboratories management and staff were actively engaged in this review activity. Corrective or compensatory actions were taken or initiated for most of the specific deficiencies identified by the team, and some individuals or organizations were observed to be proactive in resolving safety issues. Senior NIST management recognizes the need for changes to improve safety management and is drafting a corrective action plan.

However, the Special Review team identified a significant number of unsafe or unanalyzed conditions with the potential to cause harm to workers, as well as some concerns about potential environmental impact. Previous NIST efforts to establish a safety management system have not progressed beyond the development of upper-level program documents, and many existing safety program documents have not been used or kept current. The need for a safety management system has not been adequately communicated or accepted. Instead of establishing management systems, there is an overreliance on individual workers' ability to identify hazards and implement controls. While many individuals exhibited knowledge of certain hazards and controls associated with their work activities, they did not always have the requisite knowledge or an established safety management system to identify and analyze all hazards and controls.

Establishing a systematic approach to managing safety is essential to resolving these weaknesses and preventing the recurrence of the significant number of unsafe or unanalyzed conditions identified by the Special Review team. A project management plan, with assigned responsibilities, scheduled milestones and completion dates, and resources required to complete the tasks, is needed to ensure that these management systems are established in a timely and effective manner. Significant effort will be needed to establish a safety management system. Sustained management attention will be required to successfully establish a system that can provide assurance that controls are applied to eliminate or mitigate hazards. The system must also provide management with the information necessary to facilitate continuous improvement. NIST senior management recognizes the need to establish a safety management system that provides a systematic approach to managing safety. The opportunities for improvement provided in Appendix A provide recommendations to support establishment of a safety management system.

Appendix A
Opportunities for Improvement

1. The NIST Director and Deputy need to clearly articulate, at the Operating Unit level, the need for and purpose of a safety management system at the Operating Unit level. Operating Unit leadership must facilitate understanding and acceptance throughout the entire organization. From the outset, a primary focus of the NIST safety management system must include clear definitions of roles, responsibilities, authorities, and accountabilities at all levels of the organization.

2. NIST leadership should facilitate the establishment of a safety management system. Regardless of the system used (e.g., ANSI/AIHA Z10 or a proven system from another laboratory), the following are key to success:
   - Consider benchmarking against other laboratories.
   - Consider mentoring from other laboratories.
   - Conduct a gap analysis against the safety system chosen by NIST management, considering the need to integrate with existing management processes where feasible or the need to strengthen existing management processes.
   - Develop an action plan to close gaps, such as the lack of a process for managing requirements, that clearly defines milestones and deliverables and assigns responsibilities.
   - Consider utilizing project management techniques.
   - Develop a system description that provides a roadmap from the model system to the NIST approaches for implementation.
   - Assign a project lead, reporting to the NIST Director/Deputy, with overall responsibility to manage implementation of the plan.
   - Involve line management and workers in the development of systems and processes, such as work planning and assessment. Consider developing work planning processes for research, construction, and maintenance to ensure that all hazards are identified and assessed, controls are in place, and individuals are trained before authorizing work. Ensure that the processes address continual safety improvement through appropriate feedback mechanisms.
   - Include periodic reporting to the NIST Director on the status of and barriers to implementation.
   - Include periodic review of implementation, starting early in the efforts, to ensure that expectations are understood and barriers to successful implementation are identified.
   - Throughout this effort, management at all levels needs to communicate the need for change and the purpose of new or changed processes.

3. As the system and supporting processes are established, conduct a gap analysis of current conditions and operations and establish a plan to close any gaps identified.

4. Consider creating a Boulder Laboratories executive-level director position with responsibility and authority for operations, interfaces, and conflict resolution within site operating units and between the site and external organizations. The director would be responsible for such functions as all facility operations supporting research (including safety support), emergency management, internal and external interfaces, facility operations and maintenance, and environmental compliance activities. In addition, consider assigning specific individuals with similar responsibilities and authorities within the NIST Boulder Laboratories at the building and laboratory level.

5. Strengthen the Boulder Laboratories safety office by adding certified safety professionals, certified industrial hygienists, and a fire protection engineer.

6. In the near term, evaluate operations, facility conditions, and existing training requirements and implementation to determine the extent to which the deficiencies identified during this review exist in other NIST locations. Develop and implement a plan of action with milestones to correct these specific deficiencies.

7. NIST needs to strengthen maintenance and construction contract management. Specific actions to consider include:

   - Provide contractors with incentives for improving safety performance. Consider penalizing contractors for poor performance and rewarding them for good performance. Rewards could include granting preferred status for future contract awards. Penalties could include withholding payment or assigning a performance rating that would penalize the contractor in future contract competition. Document the process to be used, and include appropriate conditions in future contracts.

   - Better define safety and health requirements in the terms and conditions of contracts. Specifically define each applicable site requirement and industry standard in construction contracts and more fully discuss expectations for compliance at pre-construction meetings.

   - Strengthen processes for hazard analysis and control. Processes that require daily assessment of hazards and briefing of workers on hazards and associated controls can be effective in ensuring that workers are aware of these hazards and controls before they start work each day. Consider requiring contractors to include such processes in their health and safety plans.

   - Establish a program for feedback and continuous improvement in the areas of construction and maintenance safety. Improve the effectiveness of construction self-assessments by requiring construction contractors to have an onsite safety representative, dedicated full time to ensuring safety, when there are significant hazards associated with the scope of work. Establish a formal program for EMSS oversight to assign responsibilities and provide instructions for assessing and documenting contractor performance. Include requirements for analyzing performance data to support improvements in NIST programs and increased contractor accountability.

APPENDIX B
Supplemental Information

Dates of Special Review

Initial and Planning Visit	August 4-7, 2008
Onsite Visit	August 18-28, 2008

Management

Glenn S. Podonsky, Chief Health, Safety and Security Officer
Michael A. Kilpatrick, Deputy Chief for Operations, Office of Health, Safety and Security
William A. Eckroade, Director, Office of Independent Oversight
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