I. Executive Summary

A hydrogen fire occurred in an engineering laboratory at 3:30 am on October 1, 2015 when a graduate student, working alone, was trying to heat and taper a fiber optic cable in a hydrogen flame. The fire appears to have resulted from a leak of hydrogen gas from a valve of the flow meter (rotameter), which ignited. The graduate student was concerned the flame would back flash through the hose connected to the hydrogen cylinder causing the cylinder to explode, so the student tried to reach over the flame to shut off the cylinder valve. (It was later discovered the regulator on the cylinder had a flame arrestor attached, which would prevent this sort of back flash catastrophic failure.) The heat of the flame was too intense for the student to shut off the valve and the student received a small (approximately 2 inch diameter) first degree burn (red patch) on the wrist. The student exited the laboratory, called 9-911 and waited outside the building for the Fire Department. The heat from the flame set off a fire sprinkler head in the lab and sounded the fire alarms in the engineering building and adjacent buildings. Washington University Police, Facilities Planning & Management (FP&M), Environmental Health and Safety (EH&S) and other departments responded to incident. The FP&M Night Mechanic extinguished the blaze with a fire extinguisher and Fire Department personnel shut off the valve on the hydrogen cylinder.

In reviewing the incident with all involved, using the James Reason “Swiss Cheese Model of Accident Causation” as the framework for the after action analysis, it was determined that there are several lessons learned that can be implemented to prevent or minimize the reoccurrence of similar incidents. Recommendations on (1) training and education, (2) equipment, and (3) safety culture are proposed for Washington University in St. Louis students, researchers, Principal Investigators (PIs), laboratories, Departments Schools and the University. The specific recommendations are included as appendices to this report.
II. After Action Review Process

A. The University assembled a team from all the departments involved in the response to the incident. The team included the graduate student involved in the incident, the Principal Investigator, a Research Faculty representative, WU Police Department, Facilities Planning and Management, Environmental Health and Safety, School of Engineering & Applied Science (SEAS) Director of Facilities Planning & Management, SEAS Laboratory Safety & Protocol Manager, Insurance and Risk Management, Emergency Management and AirGas, the supplier of the hydrogen gas cylinder involved in the incident. Input was also provided to the team from the City of St. Louis Fire Department and City of St. Louis Police Department.

B. The team used the James Reason “Swiss Cheese Model of Accident Causation” as the framework for the after action analysis, as recommended by the U.S. Chemical Safety Board, http://www.csb.gov/texas-tech-university-chemistry-lab-explosion/. The team advocated from the start that it was not there to assess personal blame, rather its purpose was to assess what went wrong at all levels of the institution in order to correct any deficiencies to prevent future incidents and to use lessons learned as an education tool for University researchers.
III. Incident Summary

A. On October 1, 2015 at 3:30 a.m. a School of Engineering Graduate Student was working alone in the Nanomicro Photonics laboratory located in Green Hall 2041A. The laboratory contains six lasers (five Class 3B and one Class 4 lasers) on separate tables, numerous electronic devices, high voltage equipment, battery backup systems, and supplies. The Graduate Student was beginning the process of tapering a fiber optic cable using a hydrogen flame. Shortly after lighting the torch used to heat the cable, a large flame (flash) occurred directly in front of the Graduate Student. He immediately tried to shut-off the hydrogen tank but had to retreat after being slightly burned (first degree, approximately two (2) inches diameter) on the right forearm. The heat from the flame activated the nearby ceiling sprinkler head and fire alarm.

B. Review of the equipment post-event indicated that a valve on, or a portion of, a flow rotameter failed, or the valve was opened to a point that it leaked hydrogen gas. The gas ignited, causing the fire. The fire persisted due to the flow of gas from the hydrogen cylinder. The Graduate Student was not aware that the regulator on the hydrogen cylinder had a flame arrestor attached, so there was no concern of flame propagating into the tank and causing an explosion. The student felt he had to close the cylinder valve to prevent such an explosion, but the heat of the flame forced him back from the laser table.

C. The Graduate Student evacuated the room and contacted 9-911, instead of WUPD, to report the fire.

D. Due to the fire and heat, one sprinkler head activated and activated a fire sprinkler flow alarm to WUPD Dispatch for Green-Brauer-Whittaker Halls (combined).

E. The primary concern of emergency responders was life safety and verifying the Graduate Student was okay and receiving proper medical follow-up if needed, then response to the fire situation in a laboratory setting.

F. The Facilities Planning and Management night mechanic extinguished the flame using a fire extinguisher and Fire Department response personnel shut off the flow of hydrogen gas “minutes” after the flame was extinguished.

G. The primary hazards when responders initially arrived on the scene were:
   a. Fire hazard and concern of gas cylinder or gas buildup explosion
   b. Electrical hazard due to water from sprinkler system flooding rooms with high voltage electrical equipment, as well as numerous functioning power strips in water on floor
      i. After the City of St. Louis Police and Fire Department left, and only EH&S personnel and a single contractor representative were in the laboratory room assessing the incident, a secondary fire started due to wet ceiling
tile material that had fallen onto a piece of high voltage equipment on

table next to the laser table where the original fire occurred. EH&S

personnel extinguished the small fire by cutting power to the equipment

and separating and smothering the smoldering material.

c. Electrical hazard due to battery backup of systems

d. “Laser in Use” sign was lit indicating the Class 4 laser and Class 3B lasers in the

room were on and represented an eye hazard

H. Secondary hazards were numerous, but included:

  a. Slip hazards from water
  b. Sharps hazards during cleanup
  c. Verifying hazardous chemicals and gases were not impacted by incident, fire

      suppression water and response actions
  d. Water damage to building and equipment

I. In response to the primary hazard concerns, Facilities Planning & Management shut off

all circuit breakers supplying power to the laser table equipment in the laboratory. In

all, seventeen (17) breakers had to be shut off for the six laser tables. EH&S personnel

then had to shut off/disconnect any equipment and lasers powered by the battery

backup systems, approximately thirty-six (36) connections. EH&S verified all fires were

out and verified with the Principal Investigator that lasers were powered down.

J. In response to secondary hazards, the Fire Department had begun squeegeeing water to

floor drain in an adjacent room and replaced the sprinkler head so the fire suppression

system could be put back online.

  a. In moving equipment away from the floor drain in the adjacent room, Fire

     Department personnel had blocked the electrical panel where circuit breakers

     were located to shut off power to the laser tables.

  b. In moving the equipment, the Fire Department personnel unplugged an argon-

     difluoride gas silicon chip etching machine and moved it away from the localized

     exhaust vent for the silicon etching machine. EH&S and the Principal

     Investigator had to verify this represented no risk for emergency responders.

K. EH&S verified no sharps or chemical hazards were present.

L. Contractors from WWF Cleaning Service and Woodard Cleaning & Restoration

addressed slip hazard due to water on the floors and commenced restoration activities

under the direction of Facilities Planning & Management, School of Engineering &

Applied Sciences and Insurance & Risk Management.

M. Access was restricted or limited in the restoration areas.
IV. Emergency Response

A. University Police and the Facilities Night Mechanic responded to the fire sprinkler water flow alarm. Initially, they did not know the exact location of the incident, having only received a fire suppression water flow alarm notice for Green-Brauer-Whittaker Halls.

B. The St. Louis City Fire Department contacted University Police dispatch to report that they received a call about the hydrogen fire, which they described as a hydrogen explosion to the University Dispatcher. On scene, University Police, Facilities Night Mechanic and City of St. Louis Fire Department met with the Graduate Student and performed the response described above.

C. University Police contacted the following University Departments for response support:
   - Additional WU Police Department (WUPD) personnel
   - Facilities Planning and Maintenance (FPM)
   - Environmental Health and Safety (EH&S)
   - School of Engineering & Applied Science (SEAS)
   - Insurance and Risk Management

D. Outside emergency response agencies on scene:
   - St. Louis Fire Department
   - St. Louis City Police

E. Other Response groups:
   - WWF Cleaning Services
   - Woodard Cleaning & Restoration
   - AirGas
V. Lessons Learned

Lessons Learned are divided into sections for the following levels, based on the James Reason “Swiss Cheese Model of Accident Causation” framework:

- Student/Researcher
- Principal Investigator (PI)/Laboratory
- Department
- School and University

Recommendations focus on (1) Training and Education, (2) Equipment, and (3) Safety Culture for each level. Due to overlap of these issues in the various levels, there is some redundancy in the recommendations, but the recommendations do differ based on the roles and responsibilities individuals play at each level.

The recommendations are included as appendices to this report.
Appendix 1 - Lessons Learned – Student/Researcher Level

A. Training and Education:

i. Emergency Procedures: The graduate student in the laboratory did not have good knowledge of what to do in the event of an emergency. This included whether he should attempt to shut off the hydrogen cylinder regulator valve, because of fear the cylinder may explode, versus leave and report the incident. The student was confused as who to call in the event of an emergency, the WU Police at 314-935-5555, or an outside line 911 (9-911). The student was not aware of the flame arrestor attached to the cylinder regulator, which would prevent the cylinder from exploding in this type of incident and the student was working alone in a research laboratory in the middle of the night, while working with flammable gases. The section of EH&S training about emergency procedures should reviewed with all students and researchers in the laboratory.

ii. Training recommended at the Student/Researcher level includes:
   1. Review Chemical Hygiene Plan requirements about the requirements the use of a “buddy system” when working after hours in laboratories,
   2. How to respond to various incidents, such as fire, explosion, chemical exposures, laser injuries, gas cylinder mishaps, and electrical incidents
   3. Who to contact in emergencies
   4. Fire safety and fire extinguisher training
   5. Laboratory specific safety training on the equipment and hazardous materials used in the laboratory

B. Equipment

i. See recommendations in the Principal Investigator (PI)/Laboratory Section

C. Safety Culture

i. Review the Laboratory and University Chemical Hygiene Plan requirements about the requirements the use of a “buddy system” when working after hours in laboratories. Discuss and implement a plan at the graduate student and researcher level to prevent all graduate students and researchers from working alone in the research laboratories.
Appendix 2 - Lessons Learned – Principal Investigator (PI)/Laboratory Level

A. Training and Education:

i. Principal investigator should review PI roles and responsibilities outlined by the Office of the Vice Chancellor for Research, http://research.wustl.edu/Resources/Roles/Pages/PI.aspx

ii. Review Chemical Hygiene Plan (CHP) requirements found at http://ehs.wustl.edu/resources/Pages/ResourcesSearch.aspx

iii. Develop a laboratory specific training program, with assistance from the SEAS Laboratory Safety & Protocol Manager, EH&S and Emergency Management, that covers the training aspects identified in the Student/Research Level training section.

iv. Develop and document student/researcher proficiency standards

B. Equipment

i. Equipment shut-off switches should be put in remote locations, or locations away from potential mishaps for the following types of equipment:
   1. Lasers
   2. Flammable or toxic gas cylinders
   3. Electrical equipment, focusing on high-voltage equipment and equipment that presents an electrical hazard due unshielded components
   4. Utility shut-offs

ii. Given Class 3B and 4 lasers are in use in the laboratory, the lasers are not in the visible wavelength spectrum and they represent ocular burn hazards, laser protective eyewear should be plentiful and kept outside of the laboratory for use by laboratory personnel and emergency responders.

iii. Where possible, because the laboratory is full, do not use laboratory space under laser tables and along walls for storage of combustible supplies and boxes.

C. Safety Culture

i. Review messages being given students and researchers in laboratory to determine what can help prevent people from working alone in the laboratory. Discuss what can be done to prevent students from sleeping in the laboratory, as a sleeping cot was found in the laboratory where the fire occurred. Determine if pressures to complete research and publish results are unknowingly contributing to students feeling they must complete research without focusing on initial safety training (both EH&S and...
laboratory specific training) and on-going safety practices. After review, establish a laboratory safety policy with real consequences if safety practices are not followed. Lead laboratory safety training to demonstrate to students and researchers how seriously you take safety efforts in your laboratory.
Appendix 3 - Lessons Learned – Department Level

A. Training and Education:

i. The department should use this and other past near-miss incidents as a tool to educate faculty, staff and students about: emergency procedures, hazard assessment and hazard mitigation, roles & responsibilities, Chemical Hygiene Plan (CHP) and laboratory specific training requirements.

ii. Review emergency procedures and test to verify that students and employees know what to do during emergencies.

B. Equipment

i. All department laboratories should assess the need for automatic or remote shut-off switches/valves for:
   1. Electrical equipment, focusing on high-voltage equipment and equipment that presents an electrical hazard due unshielded components
   2. Utility shut-offs
   3. Flammable or toxic gas cylinders
   4. Lasers

ii. Review layout of equipment in laboratories, so egress is not blocked and critical equipment, such as the shutoff valve to a hydrogen gas cylinder in this incident, is not blocked.

iii. Assess whether adequate Personal Protective Equipment (PPE) is provided in research and shop areas, for eye protection, lab coat protection, including Flame Resistant (FR) coats as needed, hand and foot protection, and specialized shielding.

iv. Verify engineering controls, such as chemical fume hoods, gas cylinder storage cabinets and localized exhausts are adequate

C. Safety Culture

i. Review with faculty and staff the spoken and unspoken messages given students and researchers in laboratories to determine if actions are contradicting safety messaging. For example, in addition to the sleeping cot found in the laboratory involved in this incident, a blow-up mattress was found in another Engineering laboratory approximately 1.5 months prior to this incident. Discuss whether faculty wear PPE in laboratories when needed (set the right example) and do faculty hold students and researchers accountable for following laboratory safety requirements. What is the
department’s policy when safety requirements are not followed? Are the policies published and shared with departmental faculty, staff and students?
Appendix 4 - Lessons Learned – School and University Level

A. Training and Education:

i. School Level – SEAS should develop safety training specific for engineering programs
   1. Training can bring in safety experts from industry for safety symposia and/or the training can be modeled after the Chemistry Department program which initially trained all faculty, staff and students, followed by the implementation of the Chem 599 Course which is required of all incoming graduate students
   2. Topics should cover:
      a. Emergency response and fire safety
      b. Gas cylinder safety
      c. Specialized equipment safety, such as lasers, high-temperature, high pressure, low temperature, and electrical hazards
      d. Hazardous and toxic material hazards present in engineering laboratories
      e. Specialized topics can be covered in individual departments, such as blood borne pathogen hazards in Biomedical Engineering
      f. How to perform a hazard risk assessment for experimental procedures and how to develop and document safety Standard Operating Procedures (SOPs) before experiments begin to minimize safety hazards as new students researchers assume research responsibilities

ii. University Level – EH&S should share the lessons learned from this incident and others as an education piece for all researchers
   1. Share Green Hall After Action Report through EH&S “Lessons Learned” web page
   2. Share report through “Research News”

iii. University Level – EH&S and Schools – Develop process to remind students, faculty and staff about emergency procedures; develop a method to assess if the information is being understood, and will be acted on during an actual emergency.
   1. During EH&S laboratory safety audits, laboratory personnel can be asked what to do during emergencies, such as who to call and notify, and where to go.

iv. University Level (Responders)—Need to review response protocols with WUPD, Facilities and EH&S to ensure that they are responding safely to incidents.
   1. Specifically, review shutoff of utilities, equipment such as lasers, and battery backup systems, prior to response, particularly with standing or flowing water incidents.
v. University Level – EH&S should work with Schools to develop non-punitive safety reviews of research areas to improve safety
   1. A model that appears to work well at a few other institutions is peer safety reviews of laboratories within or between departments, as is done by the Joint Safety Team (JST) at the University of Minnesota and is done in the Washington University Department of Chemistry.

B. Equipment

i. A safety survey of gas cylinders, lasers and potential hazardous equipment, and materials, should be done in the School (and within the University) in light of the lessons-learned from this incident. The survey can focus on:
   1. Location of shut-off valve and switch locations in relation to work areas
   2. Use of flame arrestors and/or emergency shut-off solenoids on cylinders containing flammable and toxic gases
   3. Warnings for emergency responders about battery back-up systems that may maintain operation of potentially harmful equipment, such as open-beam Class IV lasers, or other special hazards
   4. Availability of PPE safety equipment for students, researchers and emergency responders

ii. The School should address labeling for specialized hazards. For example, the Principal Investigator (PI) in this incident said that out of the six lasers in the laboratory, only the laser on the table where the fire occurred represented an eye injury risk. However, all laser table warning signs were identical, so it was not possible for emergency responders to distinguish those lasers which represented a safety health risk from those that did not.

iii. University level – EH&S will have laboratory auditors check to see if flame arrestors are used on flammable gas cylinders, which are used for open flames in research laboratories.

iv. University level – Facilities Planning & Management and WUPD will assess the potential of separating fire sprinkler water flow alarms, such that WUPD can distinguish at a minimum which of the three buildings, Green, Brauer, or Whittaker, has a fire sprinkler head that has been activated.

C. Safety Culture

i. This incident provides an educational opportunity for the University and all School research personnel to help refine and improve our laboratory safety culture. Our
Provost led a National Research Council Committee, which looked at safety culture challenges in academic laboratories. The Committee published recommendations for researchers, PI’s, department chairs, deans and EH&S for promoting safety in academic laboratories. Now is a time to review these recommendations at the department and school levels and have a dialogue on what are, and what should be, our culture and expectations at Washington University in St. Louis. The dialogue should include when and where students can work alone, if ever, what is the minimum PPE that is needed to be worn in different types of research settings, what is leadership’s role in shaping the culture, what is the baseline training and education expected for all faculty, staff and students, and what are consequences if the safety culture is not followed. If this were a simple issue, there would be no need for dialogue, but there are differing opinions in our highly de-centralized environment on what safety practices and expectations apply in the many differing laboratories across our University. (There are approximately 700 laboratories and 3000 laboratory rooms across the institution.) While EH&S has published safety policies and guidelines that meet U.S. Occupational Safety & Health Administration (OSHA) and the National Research Council requirements or recommendations, some researchers believe some of the requirements are overly burdensome and do not accurately take into account the actual risk in their laboratories. It is hoped that after the discussions occur, all can agree on the safety expectations that should apply to, and can be documented for, our institution.
Appendix 5 – Photos From the Incident

Torch Head for Hydrogen Gas Flame
Torch Head for Hydrogen Gas Flame

Hydrogen Cylinder

Flow Meter

Argon Cylinder

Torch Head for Hydrogen Gas Flame
Flow Meter

Flow Control Knob where flame appears to have originated
Flashback Arrestor on Hydrogen Line
High voltage equipment, which started secondary fire after Fire Department Left.