DESIGNING A FIRE-TESTING LABORATORY FOR THE UNIVERSITY OF COSTA RICA

Report Submitted to:

Engineers of Costa Rican Fire Department

Mechanical Engineering Department of the University of Costa Rica

Written By:

Michael Berlied

Elena Fajardo

Andrew Mackenzie

Chelsea Tuttle

December 14, 2010

DESIGNING A FIRE-TESTING LABORATORY FOR THE UNIVERSITY OF COSTA RICA

Interactive Qualifying Project Report completed in partial fulfillment
of the Bachelor of Science degree at
Worcester Polytechnic Institute, Worcester, MA

Submitted to:

Professor Jennifer Rudolph and Professor Stanley Selkow

In Cooperation With:

Engineers Patricio Becerra and Marcela Shedden of the University of Costa Rica
and
Chief Engineer Esteban Ramos and Engineer Jacinto Saborío
Fire Department (Bomberos) of Costa Rica

Printed Name	Signature
Michael Berlied	______________________
Elena Fajardo	______________________
Andrew Mackenzie	______________________
Chelsea Tuttle	______________________

December 14, 2010

____
Jennifer Rudolph (Advisor)

____
Stanley Selkow (Advisor)

ABSTRACT

This project researched and designed a fire-testing laboratory for the University of Costa Rica (UCR) to allow its sponsors, UCR and the National Fire Department of Costa Rica to establish their undergraduate Fire Protection Engineering program and test fire properties of common construction materials. The project team developed qualitative and quantitative analysis tools to prioritize instruments for the laboratory. Based on results, the team recommended five pieces of equipment for the laboratory that most closely meet both sponsors' needs, as well as safety measures and a computer-generated layout. Once established, this laboratory will enhance fire protection education and improve fire-fighting techniques in the country.

ACKNOWLEDGMENTS

We would like to take this opportunity to thank those people that put time and effort into helping us complete this project:

Patricio Becerra: Mechanical Engineer and Professor of Mechanical Engineering for the Universidad de Costa Rica
Esteban Ramos: Civil Engineer of Costa Rican Fire Department
Jennifer Rudolph: Resident advisor for Costa Rica Project Center
Jacinto Saborío: Engineering Department of the Costa Rican Fire Department
Stanley Selkow: Resident advisor for Costa Rica Project Center
Marcela Shedden: Chemical Engineer and Professor of Mechanical Engineering for the Universidad de Costa Rica
Ingrid Shockey: WPI on-campus advisor and preparation professor

We would also like to give special thanks to the entire **Engineering Department of the Costa Rican Fire Department** for allowing us to use their office space as well as providing many lunches, birthday parties for Michael and Chelsea, and for great memories. We would also like to thank **The University of Costa Rica** for providing classrooms during meetings and for allowing us to use their library. We also wish to thank **Apartmentos Tairona** from providing a fantastic place to stay for the seven weeks. Finally a special thanks to **Worcester Polytechnic Institute** for giving us the chance to go abroad and work on a great project in Costa Rica.

EXECUTIVE SUMMARY

In March 2010, a fire broke out in the laundry facilities of Hospital México in San José, Costa Rica. The dryer had heated the blankets to the point where the oily residue leftover from production of the blankets reached its ignition temperature. When the blankets were placed in a laundry basket after drying, they self-combusted. This fire was extinguished before harming anyone, but it had the potential to injure or kill hundreds of patients and employees of the hospital.

Between January and September of 2010, a total of 190 investigated fires in Costa Rica killed 16 people and injured 829 others. Additionally, fires have consumed a total of 174,308 square meters of property since January 2008. Accidents like the one described above occur in part because Costa Rica does not have the means to test materials for fire properties. Therefore, the national fire department of Costa Rica (El Cuerpo de Bomberos) together with the Universidad de Costa Rica (UCR) want to design and implement the first fire-testing laboratory in their country. The Bomberos want to use this laboratory to test for and investigate fire properties of materials imported from other countries. This will enable them to improve fire prevention throughout the country, conduct more accurate investigations, and fight fire more effectively. UCR wants to use this laboratory to supplement mechanical engineering courses geared towards educating students in fire science.

Since 2007, UCR has been making progress in the development of this laboratory. They have already purchased a Microscale Combustion Calorimeter and a Smoke Chamber, and are currently in the process of installing this equipment in the Mechanical Engineering laboratory on the San Pedro campus of UCR. Additionally, they have created a list of fire-testing equipment they are interested in purchasing, which acted as the basis of this team's research and recommendations. The Bomberos and UCR invited Worcester Polytechnic Institute to participate in the further development of this laboratory by designing their fire-testing laboratory. The scope of this project included recommending up to five pieces of additional equipment, determining safety precautions and drawing a layout for the laboratory.

Fire-testing Equipment

In order to recommend equipment, we first determined a list of the most important

materials to test in the UCR fire-testing laboratory. To complete this objective, we utilized the Bomberos' Costa Rican fire statistics and visited three public buildings: Hospital de Heredia, Hospital San Juan de Dios and Hospital México. Because our findings included over 28 materials, we interviewed our liaisons from UCR and Bomberos to determine which of these materials they preferred to test (see Appendix C.4). Testing construction materials for fire properties was our sponsors' main concern, and this narrowed list of materials enabled us to tailor our equipment recommendations to the needs of our sponsors.

We also determined which courses of the UCR FPE curriculum will utilize fire-testing equipment. We used course descriptions that our sponsors provided and fire properties research to determine that three out of the nine courses can benefit from a fire-testing laboratory component. These courses are: Análisis de Riesgo (Risk Analysis), Química para Protección Contra Incendios (Chemistry for FPE) and Dinámica del Fuego (Fire Dynamics). We used these courses to determine which pieces of equipment would supplement UCR's FPE curriculum.

Once we established the above criteria, we researched the specifications of each piece of fire-testing equipment on UCR's list. We determined the materials the equipment tests, the fire properties it measures, the FPE courses it supplements, and the standards it follows. We researched these specifications online by visiting the websites of the manufacturers, such as Govmark and Fire Testing Technology. We constructed a spreadsheet to organize and compare all of this information.

Using our equipment data spreadsheet, we conducted both qualitative and quantitative analyses of the equipment. The qualitative analysis tool eliminated pieces of equipment from the list that did not meet the following four of our sponsors' criteria: 1) it performs prescriptive-based tests 2) it follows ASTM or ISO standards 3) it tests construction materials and 4) it supplements UCR's FPE courses. For the quantitative analysis tool, we used a grading rubric that we created (see Appendix E.6) to rank the remaining pieces of equipment from most to least relevant to our sponsors' needs. Based on the outcomes of our analysis tools, ***we recommend that UCR purchases the following five pieces of equipment:***

1) The Cone Calorimeter

With the Cone Calorimeter, researchers will be able to test many different properties of materials, as outlined in section 4.3.2 of the Findings and Discussions chapter. They will be able to calculate how long a specimen will take to ignite and how long it will burn for. Additionally, they will observe how the specimen reacts with fire and the byproducts it emits during combustion.

2) The Single Burning Item Test

The SBI will be very useful because users will observe how construction materials react with fire. They will ignite a larger specimen of material and observe its behavior, including how fast the flame spreads, how long it burns for, and how much smoke it produces.

3) The Radiant Panel Flammability Tester

This piece of equipment will allow researchers to observe the manner in which flame will spread, including the time it takes to ignite, and the speed and distance that the flame grows. It uses radiant heat as an ignition source instead of a direct flame, enabling researchers to understand the effects of heat alone and how high temperatures can start and contribute to fires.

4) The Horizontal and Vertical Flame Spread Tester

With this piece of equipment, users will observe ignition and how a flame spreads and reacts with materials when exposed to a direct flame. It tests parts in electrical devices and appliances, which are the main cause of fire in Costa Rica and are thus important for our sponsors to understand.

5) The Non-Combustion Flammability Tester

This piece of equipment will enable researchers to test how readily a material will ignite using a radiant heat source. This information can help prevent incidents such as the hospital blanket fire, which ignited without a flame source.

Laboratory Safety

Based on our equipment recommendations, we determined safety precautions of the laboratory to ensure the safety of both users and equipment. We researched NFPA and Inteco codes and used private websites to identify information regarding the selection and installation of active suppression systems. These systems included automatic sprinklers and fire extinguishers.

From our research on safety precautions, we found that NFPA standards require active fire suppression for this fire-testing laboratory. NFPA 10 and 13 detailed the requirements for fire extinguishers and sprinklers systems respectively. Using these standards, ***we concluded that UCR should obtain and install a type ABC dry chemical extinguisher, a type BC carbon dioxide extinguisher, and a standard pendent automatic sprinkler system*.**

We also researched supplementary safety features such as gas detectors and emergency eyewash and shower stations because they ensure a safer laboratory environment. We referred to NFPA 72 and 720 as well as ANSI Z358.1, which cover these topics. We found that appropriate gas monitors and an emergency eyewash and shower station are necessary for the laboratory. ***We concluded that UCR San Pedro should choose, purchase, and install a gas monitor and a combination emergency eyewash and shower station in the laboratory*****.**

Layout Design

Using all of our above recommendations, we generated a layout of the fire-testing laboratory at UCR San Pedro. We measured all dimensions of the existing Mechanical Engineering laboratory and created a two and three-dimensional sketch of the empty room using Autodesk's Revit Architecture 2011. We then used the empty model to create an object-oriented layout of the laboratory which included our recommended equipment. ***We concluded that the laboratory should be arranged according to our recommended design.***

Conclusion

The UCR laboratory will be the first fire-testing laboratory in Costa Rica, which has greater implications than only testing fire properties of construction materials. As UCR students use the laboratory they will have a better understanding of the relationship between fire and materials than classroom training alone can provide, and they will be more prepared to enter a career field in fire protection. With each graduating class becoming involved in design or construction of new buildings, there should be noticeable improvements in the fire safety of buildings in Costa Rica.

The Bomberos will also benefit from the laboratory. They will better understand how fire behaves with different materials commonly found in Costa Rica. This will help the Bomberos improve their firefighting abilities and investigation skills, and therefore improve the fire-safety of the country. Finally, this fire-testing laboratory will help save lives. Fire kills many people all over the world, and Costa Rica can minimize fire-related deaths as a direct result of the lessons learned in this testing laboratory.

AUTHORSHIP PAGE

The following is a breakdown of the research and writing contributions of each group member toward the completion of this final report.

Michael Berlied wrote about standard test methods and laboratory sizes in the background chapter. He contributed to the quantitative analysis section of the methodology chapter and was also responsible for writing parts of the equipment recommendations section. Also, Mr. Berlied combined and organized the appendices and the final report into one cohesive document.

Elena Fajardo was responsible for the explanations of different fire properties in the background section. Ms. Fajardo also wrote the methods and findings for the materials sections and the qualitative equipment analysis tool. In the recommendations chapter she contributed to the equipment and laboratory layout sections. She was also the prominent note taker at sponsor meetings and during building visits and therefore contributed to Appendix E.

Andrew Mackenzie wrote the background chapter's laboratory safety sections. He was also responsible for writing the methods and findings for the safety needs of the proposed laboratory. In Chapter 5, he wrote the safety recommendations and also contributed to the future expansion recommendations. Mr. Mackenzie produced the recommended laboratory layout using his expertise with Autodesk's Revit Architecture.

Chelsea Tuttle conducted the case study within the background chapter as well as wrote the previous developments section. Ms. Tuttle also described the methods used for researching the fire equipment and designed the rubric for the rankings of the quantitative analysis tool. She wrote the findings section for the quantitative analysis and contributed to the future expansion recommendations of Chapter 5. She was also the strongest editor of the group.

Michael Berlied, Elena Fajardo, Chelsea Tuttle and Andrew Mackenzie all contributed to the final editing of each chapter and reviewed the final report for flow. The entire group also wrote the Introduction and Executive Summary chapters together as a team.

TABLE OF CONTENTS

List of Figures

List of Tables

1.0 INTRODUCTION

Between January and September of 2010, fires killed 16 and injured 829 people in Costa Rica. Additionally, fires consumed a total of 174,308 square meters of property since January 2008. Over the past three years, 25.1 percent of all investigated fires were caused by failed electrical systems, the top cause of fire in Costa Rica (Ingeniería de Bomberos, 2010). Deterioration in the integrity of electrical wires causes a majority of these incidents. Other materials can cause or aid in the growth of fire as well. For instance, in March 2010, a small fire broke out in Hospital México after recently dried hospital blankets were placed into a laundry basket. The dryer heated the residues left on the blankets from production until they reached their ignition temperature, at which point the blankets self-combusted. While this fire did not claim any lives, it surprised the hospital that a common habit such as drying blankets could start a fire because of unknown substances in the blankets (Jacinto Saborío, personal communication, November 9, 2010). Accidents like these occur in part because Costa Rica does not have the means to test materials for fire properties.

In order to prevent similar incidents in the future, El Cuerpo de Bomberos, the National Fire Department of Costa Rica, together with the Universidad de Costa Rica (University of Costa Rica or UCR), want to design and implement a fire-testing laboratory that will test for and investigate fire properties of materials. With these means, Costa Rica will be able to certify the fire resistance of materials as well as educate future fire protection engineering students in fire safety.

The UCR sponsors have established a list of equipment to purchase, and within the next two years they want to buy three to five pieces of equipment that will help educate the mechanical engineering students at UCR. This laboratory will supplement fire science courses at UCR by testing various construction materials' reaction to fire.

Having this resource and knowledge is important to the Bomberos because engineers and fire officials will be able to work towards bettering fire prevention throughout the country. For example, if fire fighters better understand fire behavior they will have a heightened awareness of their safety and will be able to fight fire more effectively. Understanding fire reaction in different materials can also help in the prevention of fires in buildings because it will help designers choose safer materials. Additionally, our sponsors and their collaborators will be able to test materials that they purchase to ensure safety and adherence to standards asserted by manufacturers.

Over the past three years, UCR made progress in the development of this laboratory. They have begun to incorporate fire-safety and dynamics courses into their mechanical engineering curriculum, using the syllabi from the University of Maryland, which has a well-known and respected fire protection engineering program, as a guideline. They have also purchased some equipment from their list, such as the Microscale Combustion Calorimeter and a Smoke Chamber. Additionally, UCR is involved in the construction of a new laboratory space in the province of Alajuela. Because UCR is a government-funded institution, there is a budget for the development of the Fire Protection Engineering (FPE) program, which is reviewed every five years. While we recognize the budget as a limitation for the progress of the laboratory, we will not be regarding it as a restriction for our recommendations per request by our sponsors.

While our sponsors have been working on this project for the past three years, they also have many plans for the future. In 1-2 years they want to have a fully functioning laboratory at the San Pedro campus of UCR. They will install equipment in the former mechanical engineering laboratory and will use it to supplement the FPE courses. In 4 to 5 years, UCR will move the equipment at San Pedro to the Alajuela laboratory. They then want to be able to use this new laboratory to certify the fire resistance of materials. For UCR, certifying materials means ensuring that purchased materials are indeed fire-resistant before relying on them for protection against fire. In this way they can verify the manufacturer's claims of fire-resistance. With this fire-testing laboratory there is room for further research and development. For example, in the future, UCR could improve their laboratory and work towards creating an internationally accredited program.

The goal of this project was to recommend pieces of equipment, safety precautions and physical properties for the fire-testing laboratory. In order to determine the most relevant pieces of equipment for the laboratory, we analyzed a wide variety of fire-testing equipment both qualitatively and quantitatively. Afterwards, we considered the recommended equipment and their specifications so that we could recommend proper safety precautions. We finally created a layout of the laboratory, which included the recommended equipment. This project is important to our sponsors because having a fire-testing laboratory will allow the Bomberos and students from UCR to test and understand the fire-resistance of materials. Also, in the future, qualified personnel can certify the fire-resistance of materials. Furthermore, it can become an example for other countries in Central America in the development of Fire Protection Engineering.

2.0 BACKGROUND

Because Costa Rica currently does not have a laboratory to test for fire properties of materials, UCR and the Bomberos are heading this project to create one at UCR. It is important to understand the many different aspects involved in a fire-testing laboratory. This background chapter contains information on the importance of fire-testing, an introduction to fire properties of materials, how fire-testing standards will affect the development of the laboratory, types of laboratories, laboratory safety, case studies, and the progress and development of this project.

2.1 IMPORTANCE OF FIRE-TESTING

Around the world fires claim innumerable lives and cause great amounts of property loss. Implementing advances in technology, such as following fire safety standards and using fire-resistant materials, can prevent future fires and reduce damages. Therefore, analyzing how materials react with fire can ameliorate construction and increase safety. Fire-testing can generate a better understanding of fire behavior and can lead to improved safety standards for materials, products, buildings and transportation (Lawson, 2009).

From the 16th century through the 18th century, there has been significant growth in science and technology that has provided the foundations for fire testing. There have been constant improvements in fire-testing methods since the first fire test, conducted less than 300 years ago. When societies became more populated and industrious, large fires with catastrophic consequences in major cities triggered the need for fire-testing. Some famous fires in North America include the Great Fire of New York (December 16, 1835), the Great Chicago Fire (October 8-9, 1871) and the Great Boston Fire (November 9, 1872) (National Fire Protection Association, 2008). Because of fires like these, in the early 1900's cities began to adopt the fire-testing standards as part of building codes and regulations in order to reduce the loss of life and property from destructive fires (Lawson, 2009).

2.2 FIRE PROPERTIES OF MATERIALS

When testing fire properties of materials, there are two main characteristics of fire performance in any material or space: 1) fire endurance and 2) reaction to fire. Fire endurance, also defined as fire resistance, refers to the performance of a structure or given material in a fire. It answers the questions: will a structure collapse during the fire? Or will its internal components fail? This characteristic is usually more qualitative. On the other hand, reaction to fire is more quantitative and it includes ignitability, heat release rate, smoke production rate and fire growth. These are some of the common measurements in fire tests (Babrauskus, 1990).

2.2.1 IGNITABILITY

Ignitability answers the question: how much time can a material or product be exposed to fire of a specific temperature before it catches on fire? Qualitatively, one can also ask, how easy is it to ignite a material? Is a material prone to self-heating, and if so, will it ignite? This issue should be addressed when it comes to fire safety of materials. Oxygen, heat, and fuel must all be present in order for a product or material to ignite. These three elements comprise the triangle of fire, and removing one of them results in the fire reaction discontinuing (Quintiere, 1998). It is more difficult to heat the surface of a cold material to its ignition temperatures than the surface of a warm one. Consequently, warm materials are easier to ignite. Therefore, temperature is the main factor in the occurrence of ignitability (Ames, 2002).

2.2.2 HEAT RELEASE RATE

Heat release rate (HRR) quantifies the answer to the question: "How big is the fire?" (Babrauskus, 1990, p.V). It is the most studied measurement in fire protection engineering as it evaluates the fire development in materials and products. Furthermore, it is "the single most important variable in characterizing the 'flammability' of products and their consequent fire hazard" (Babrauskus & Peacock, 1991. n.p.). HRR defines other measurements, such as smoke release rate, toxic gas release rate and gas temperature, because they are dependent on HRR. This value also contributes to the understanding of a material's burning rate, which can be used to model fire growth (Tran & White, 2004). Since heat is measured in units of Joules, HRR is measured in Joules per second, also referred to as Watts. Several measurements are involved in the computation of the HRR of a material (Anderson et al., 2001). The best way to measure HRR is with the principle of oxygen depletion calorimetry. This method is based on the "empirical observation that heat released by burning materials is directly proportional to the quantity of oxygen used in the combustion process" (Fire Testing Technology Ltd, 2007, n.p.). A less common way of measuring HRR is through carbon dioxide and carbon monoxide (CGR) production measurements.

2.2.3 Smoke Production Rate

Another important quantity to determine during fire-testing and classification of materials is Smoke Production Rate (SPR) (Andersson et al., 2001). Smoke includes “gaseous products, liquid droplets, and solid particles called soot or particulate” (Hasegawa, 1990, p.136). Smoke and toxic gas inhalation causes many fatalities in fires than burns (Centers for Control and Prevention, 2010). Therefore, the understanding of SPR of materials can improve fire safety in buildings. There are two ways to measure smoke production: 1) collect and filter some of the smoke gases and then measure the weight of the particles or 2) measure the transmission of light through the smoke. SPR is usually measured simultaneously with HRR and flame spread (Andersson et al., 2001).

2.2.4 Fire Growth and Flashover

The growth of fire depends on the manner in which flame spreads. Testers can observe either the vertical spread or the horizontal spread of the flame. This measurement is sometimes difficult to quantify as the growth period depends on many factors. In a building, factors such as ventilation, configuration of a room, and the amount of gas affect how fast a flame spreads since these elements are part of the triangle of fire. Growth of fire in a building is also more dangerous than an open fire. A critical moment in a building is when the flames reach the ceiling (Stollard and Abrahams, 1991). This will then start to cause a smoke layer to form, which becomes hotter and thicker as more of the furnishings burn below the smoke layer (Ames, 2002). As a result, the smoke will emit thermal radiation downwards to the other objects. If the smoke layer creates enough thermal radiation, it can cause the other combustible objects in the room to reach their ignition temperature, and all will simultaneously catch on fire in 3 to 4 seconds. This occurrence is known as flashover, and causes a large change in the size and severity of the fire. However, once this occurs, the fire is in its stable phase (Stollard and Abrahams, 1991).

2.3 Fire Laboratory Standard Test Methods

Fire-testing standards provide procedures and guidance for testing methods in fire laboratories and the equipment used. The British Standards Institution defines a standard as “an agreed, repeatable way of doing something. It is a published document that contains a technical specification or other precise criteria designed to be used consistently as a rule, guideline, or definition". Individuals, companies, testing facilities, and many other parties voluntarily adopt these standards in an effort to uphold common expectations (British Standards Institution, 2010, n.p.).

In addition to standards there are identifiable codes, which are essentially standards that are imbedded within government-written laws. Codes are legally mandatory standards that a government designates for certain qualifications. For example, building codes are mandatory minimum requirements to which contractors or builders must legally abide. Costa Rica has adopted NFPA codes, which define the fire-system requirements for new buildings. On the other hand, industry and other institutions voluntarily adopt standards as best practice for whatever the standard describes (Coad, 2010).

There are many companies worldwide that produce standards for both international and domestic use. Some of these companies include ASTM International (which was formerly known as American Society for Testing and Materials, ASTM), International Organization for Standardization (ISO), National Fire Protection Association (NFPA), Aenor, British Standards Institution Group (BSI), and many more. While all of these companies produce standards that can be used internationally, each company's standards differ according to country of origin. For example, Aenor is the Spanish Association for Standardization and Certification, whereas the BSI Group produces standards intended for the European industry. ISO and ASTM are forums or networks comprised of national standards institutes, like Aenor or BSI, which strictly produce international standards (Aenor, 2010; International Organization for Standardization, 2010; ASTM International, 2010).

When fire laboratories adopt standards specifically used for fire testing, the standards provide an effective and reliable procedure for consistent testing methods. These adopted test standards are specific to the equipment that is present. For example, test standard ASTM E1354 titled 'Standard Test Method for Heat and Visible Smoke Release Rates for Materials and Products Using an Oxygen Consumption Calorimeter' describes the standard test method for use in a cone calorimeter (ASTM International, 2010). While some pieces of fire equipment specialize in single testing standards, other pieces of equipment support many different testing standards. Following these standard test methods is a necessity for any fire laboratory.

2.4 PRESCRIPTIVE BASED VERSUS PERFORMANCE BASED METHODS

Prescriptive and *Performance* are the two classifications of building codes, and because codes and standards provide guidelines for constructing buildings and structures, they also give direction for the types of tests run in a laboratory. Therefore these two classifications have developed into the two different schools of thought pertaining to testing and design within the scope of fire safety around the world.

Prescriptive-based codes define a set of requirements without stating particular objectives. “They prescribe specifically what to do in a given case” (Hadjisophocleous, 2001, p. 2). Prescriptive-based testing methods produce qualitative data that can be used for rankings or descriptions, but typically have no quantitative value. An example can be found in ASTM E119 – 10b Standard Test Methods for Fire Tests of Building Construction and Materials. By exposing a material to a controlled temperature over a specific period of time, the purpose of this test is to evaluate the duration that a material can withstand fire while preserving structural integrity. Although data produced in these tests is difficult to relate to material properties because they test the quality of a material, it can be used in comparison with other materials and for construction purposes (ASTM International, 2007; Hadjisophocleous, 2001; Karlsson, 2002; Tavares, 2008).

Performance-based codes differ from prescribed codes in that they offer an objective while leaving the means of reaching this objective to the discretion of the designer. According to this school of thought, “every building should be evaluated according to its specific geometric features, its use and its occupancy” (Hadjisophocleous, 2001, p.9). Performance-based testing methods require that there be a distinct scientific application for the quantitative data and results collected from a given test. A common performance-based test is the ASTM E1354 Cone Calorimeter method. This test measures heat release rate (HRR), mass loss rate, time to ignition, carbon monoxide and carbon dioxide production, and more. These results are directly related to material properties and can be used in engineering applications (Fire Testing Technology Ltd., 2007; Beyler, 2001; Karlsson, 2002).

For the application of the fire-testing laboratory at UCR, our sponsors wanted equipment that produces qualitative data. As a result, they were interested in prescriptive-based test equipment. The main reason for this preference was that the mechanical engineering students who will be using the laboratory do not have the chemical background or education required to run or analyze data produced in many of the performance-based tests (Marcela Shedden, personal communication, October 22, 2010).

2.5 Fire Laboratories and Equipment

Fire laboratories around the world vary in size and purpose. Dr. Nicholas Dembsey, an associate professor of fire protection engineering at Worcester Polytechnic Institute and a recognized expert, states that there are three categories of laboratory sizes that encompass all fire laboratories and equipment. They are micro-scale, bench-scale, and large-scale laboratories. These size classifications are also used in commercial settings, such as FM Global and the National Institute of Standards and Technology (NIST) (FM Global, 2010; The National Institute of Standards and Technology, 2010). Each size denomination includes unique equipment as well as distinctive purposes in fire-testing. Most laboratories incorporate some or all of the three sizes of equipment depending on the amount of space available. Large-scale laboratories are not important to this project because UCR does not have the money or space required for this size of laboratory (Nicholas Dembsey, personal communication, September 20, 2010).

2.5.1 Micro-scale Laboratories

Micro-scale laboratories and the related equipment are the smallest of the three types of fire-testing laboratories. The equipment itself can usually fit on a tabletop or counter. The term micro-scale comes from the sample size used in the equipment it describes; it refers to the milligram sample sizes that are used in the equipment. In a micro-scale laboratory, researchers perform different kinds of tests but due to the small samples, collected data is usually chemical-based. Testers also run fire resistance and fire reaction tests. Micro-scale experiments include both combustion based and non-combustion based tests.

There are multiple fire properties that micro-scale tests can analyze. Thermogravimetric testing, which subjects samples to elevated temperatures over specific time intervals, is prominent in micro-scale material testing. This testing can measure a sample’s mass reduction over time as well as the sample’s chemical reactions during elevated heating at specific time intervals (TA Instruments, 2010). One example of micro-scale equipment is the Govmark MCC-1 Microscale Combustion Calorimeter. UCR has already purchased this piece of equipment for their laboratory (see Figure 1 on following page). As stated on the product specifications from the Govmark website for their MCC-2 model, this piece of equipment tests and measures multiple fire properties with sample size range of 0.5 milligrams to 50 milligrams. Potential measurements include heat of combustion, ignition temperature, heat release rate, heat release capacity, and flame resistance. Also included in the product description is the standard that this testing device and its tests fall within, namely ASTM D7309 or 'Standard test method for determining flammability characteristics of plastics and other solid materials using micro-scale combustion calorimetry' (ASTM International, 2010; Govmark, 2010).

There are very few safety concerns or protocols for waste management for micro-scale testing because of the small sample size and small equipment size, which limit the amount of risk for potential problems. Micro-scale testing provides the least exposure to airborne toxins. The small sample also produces little smoke, and if the sample were to come loose from the apparatus it is small and localized for easy cleanup. This small sample size also makes for easy waste management; material waste can easily be disposed of in an ordinary trashcan, unless the material tested is known to be toxic or unsafe. A standard laboratory fume hood is necessary for possible smoke production from a test, even with the very little smoke of the small sample size (Microscale Chemistry, 2002).

Figure 1: Microscale Combustion Calorimeter

2.5.2 BENCH-SCALE LABORATORIES

Bench-scale testing is the mid-range scale of testing. Sample sizes and overall equipment sizes are bigger than micro-scale but smaller than large-scale. Bench-scale tests typically measure flammability characteristics such as ignitability, flame spread, heat release rate, and smoke and toxic gas production. There is equipment specific to each of these properties as well as equipment that can test for several of these at once (Janssens, 2010).

Bench-scale tests serve to simulate real-scale fire behavior and are less expensive than large-scale fire tests. However, data collected from these tests can be limited because it is only relevant to specific geometry and ignition scenarios. Bench-scale testing often subjects materials to thermal exposure rather than direct combustion, representing pre-combustion stages in a real fire. However, there are many bench-scale tests that require combustion, for example flame spread tests and smoke density testing (Apte, 2006).

Sample sizes for bench-scale fire-testing vary greatly because of the variety of equipment and tests that are used. One of the greatest benefits of bench-scale testing as compared to micro-scale testing is that the required samples are large enough to visually observe during the fire test, allowing those using the equipment to gather both technical data with a computer and visual observation data. Also, because of the size of the samples, the users can test common materials for fire resistance and other properties that manufactures make claims to. This can include building materials (such as wires, wall coverings, floor materials, etc.) as well as plastics, cloths, and metals.

These bench-scale tests only subject the samples to heat or combustion, which allows for easy and safe waste management protocols. Once a test has been completed, the sample is safe to dispose of in mainstream waste. Safety precautions however are greater than those of the micro-scale testing because of the larger equipment and sample sizes. In the event of an emergency, fire extinguishers and water hoses must be present. A larger fume hood is also necessary to manage the greater amount of smoke production due to the added mass and size of the samples (Harris, 2010).

2.6 Laboratory Safety

The NFPA defines Fire Protection Engineering as "the science of reducing loss of life and property by fire, including both prevention and fire extinguishment, by public or private means” (National Fire Protection Agency, 2010, n.p.). This drive to produce a safer world can itself be a very hazardous profession. Whenever tampering with fire, even for experimental purposes in a controlled environment, there are many factors that can go awry. Accidents that can occur in a fire laboratory include injuries, equipment damages, power failures, explosions, and ventilation failures (Benedict, 2004). Therefore, both the UCR San Pedro and proposed Alajuela fire-testing laboratories should implement sufficient safety measures to ensure an operationally secure environment.

Within fire protection, there are two principal divisions that have their own roles. The first type of fire protection is passive protection. This includes any indirect method to deter or stop fires from spreading, such as fire resistant foam insulation as well as fire resistant building materials such as drywall (Health and Safety Executive, 2010, p.2). On the other hand, active fire protection "extinguish[es] the fire, control[s] the fire, or provide[s] exposure protection for the prevention of domino effects" (Health and Safety Executive, 2010, p.1). Examples of active fire protection systems include automatic fire sprinklers, portable extinguishers, or foam dispensing systems.

The NFPA has multiple codes and standards for the installation and standardization of common physical safety features such as fire extinguishers, sprinkler systems, hoses, and carbon monoxide detectors. For instance, the code NFPA 13 "provides the minimum requirements for the design and installation of automatic fire sprinkler systems." These standards provide important technical information for the respective safety equipment, which includes their specific purposes, possible approaches and alterations, and installation and maintenance details (National Fire Protection Association, 2010, n.p.).

The sponsors at UCR wanted both the temporary laboratory at San Pedro and the proposed laboratory in Alajuela to have appropriate safety precautions to support a learning environment (Marcela Shedden, personal communication, October 29, 2010). Fire protection features would add to the safety of the laboratory by providing the future users with the means to detect and prevent accidental fires. Although UCR wanted these safety features for both locations, there were restrictions regarding the temporary fire-testing laboratory at UCR San Pedro. The room was already acting as a mechanical engineering laboratory and was filled with machinery. Although UCR will remove all of the mechanical engineering equipment in order to convert it to a fire-testing laboratory, the overall structure of the room will remain the same (Marcela Shedden, personal communication, November 3, 2010). This will possibly affect the feasibility of using some safety systems, such as a sprinkler system, which will have required alteration of the room or possibly the entire engineering building at UCR San Pedro. However, our sponsors from UCR did not want us to consider this as a limitation. They preferred receiving all safety recommendations independent of feasibility because they have the influence to make substantial changes within UCR. They understand the importance of a secure fire-testing laboratory and adherence to fire safety standards.

2.7 CASE STUDIES

To design a fire-testing laboratory for UCR, we investigated 3 university-level fire facilities as case studies to obtain insight into the types of equipment used in various laboratories. We examined laboratories and their equipment at the University of Maryland in College Park, Maryland, USA, University of Canterbury in Christchurch, New Zealand and Worcester Polytechnic Institute in Worcester, Massachusetts, USA. While the case studies analyses did not necessarily determine our recommendations we used them to determine whether standards existed in the selection of equipment and the developing of a laboratory at the case study schools. We compiled the collected information into a chart (see Table 1). Each piece of equipment is described in detail in Appendix A. After our investigation, we found that there exists no standard or trend when choosing equipment for a fire-testing laboratory. Equipment varies with the specific needs and purposes of a laboratory (Rangwala, 2010; University of Canterbury, 2010; University of Maryland, 2009; Worcester Polytechnic Institute: Department of Fire Protection Engineering, 2010, n.p.).

Table 1: Comparison of Laboratory Equipment Between Three Universities

University of Maryland	University of Canterbury	Worcester Polytechnic Institute
Cone calorimeter	Cone calorimeter	Cone calorimeter
Smoke chamber	Reduced scale and flame spread technique	Fire Propagation Apparatus
Lateral ignition and flame transport test	Lateral ignition and flame transport test	Room calorimeter
Compartment fire test facility	Wind tunnel	Differential scanning calorimeter
Vertical radiant panel	Small-scale furnace	Thermogravimetric analyzer
	Atrium	Fume hood
	Water mist system	Laser doppler anemometer
	ISO ignition apparatus	Environmental chamber
	Furniture Calorimeter	Round hot plate test apparatus
Computer applications	Computer applications	Computer applications
		V-shaped hot plate test apparatus
		Sieve shaker
		Mass flow controllers
		Precision micro-feeder
		IR gas analyzer
		High Speed Camera
		Precision mass balance

2.8 PREVIOUS DEVELOPMENTS

Since 2007, our sponsors from UCR and the Bomberos have already made progress in establishing this laboratory, including advances in coursework, land development, and purchased equipment. They have begun to incorporate fire science courses into the mechanical engineering curriculum, and have plans for future additions as well. Using the FPE curriculum from the University of Maryland, they have assimilated the following fire science courses into their own: Risk Analysis, Suppression Systems (levels 1, 2, and 3), Chemical Protection Against Fire, Electromechanical Installations, and Life Safety. In addition to these, the sponsors are in the process of incorporating the following courses: General and Laboratory Chemistry, Mechanics of Solids, Principles of Refrigeration and Air Conditioning, Fire Dynamics, and Alarms and Signals. These courses influenced our recommendations because mechanical engineering students will use this laboratory to supplement the material learned in the fire science classes.

Additionally, our sponsors are pursuing a land development opportunity in Alajuela, Costa Rica, where they plan on constructing the new fire-testing laboratory. Currently students from Universidad Nacional, the Universidad de Costa Rica, the Instituto Tecnológico de Costa Rica, and the Universidad Estatal a Distancia use multiple buildings throughout downtown Alajuela for educational purposes. The four universities participate in an inter-university curriculum program called Sede Interuniversitaria de Alajuela (SIA). The government is planning construction for an SIA building in Alajuela, which will include laboratory space for the engineering and design departments of the four universities. Our sponsors are vying for a portion of this space for the fire-testing laboratory and the FPE program. They want to be able to move the laboratory at UCR San Pedro into the new building in Alajuela in five years (Marcela Shedden, personal communication, November 3, 2010).

Since the beginning of this project, our sponsors have developed a list of equipment that they are interested in purchasing. We made our recommendations primarily based on this list. However, before we arrived on site, our sponsors from UCR already purchased some equipment, including the Govmark MCC-1 Microscale Combustion Calorimeter (along with supporting equipment such as calculators and meters) as well as a Smoke Chamber from Fire Testing Technologies Ltd. Along with the purchase of this equipment, they have been generating manuals, including standard operating procedures (SOPs) for the purchased pieces of equipment. SOPs are defined as "established or prescribed methods to be followed routinely for the performance of designated operations or in designated situations" (Merriam-Webster, 2010, n.p.). These procedures describe the requirements for carrying out all of the day-to-day operations of any laboratory.

It was our task to continue the work of our sponsors. Using this research to gain an understanding, we were able to devise a plan for choosing the best pieces of equipment for the fire-testing laboratory at UCR. This methodology and the resulting findings, recommendations and conclusions are found in the following sections.

3.0 Methodology

This project designed a fire-testing laboratory for the UCR and Cuerpo de Bomberos; the scope of the project included recommending equipment, determining safety precautions and drawing a layout for the laboratory. We identified the following objectives as necessary for completing the project:

- Determine a list of materials that UCR and the Cuerpo de Bomberos will test in the fire-testing laboratory.
- Determine which FPE courses at UCR will utilize fire-testing equipment
- Determine the details of each piece of equipment on UCR list of possible equipment, such as what fire properties each piece tests for and what standards each follows.
- Determine the laboratory safety precautions.
- Analyze the equipment to determine which are most suitable for UCR's laboratory.
- Design the layout of the laboratory based on the recommended equipment and needed safety precautions.

The dynamic nature of the project meant that objectives were interrelated and topics overlapped. However, while we researched objectives simultaneously, the completion of each individual objective relied on the completion of the previous one. This chapter describes the methodology we used to accomplish each of the objectives in order to achieve our overall goals.

3.1 Determining the Materials That our Sponsors Will Test in the Laboratory

Our sponsors wanted to know how building materials in Costa Rica react in a fire. However, due to the limited scope of the fire-testing laboratory in UCR, our sponsors cannot test all materials for their fire properties. Therefore, in order to recommend appropriate equipment for their fire-testing laboratory, we determined a list of materials that our sponsors will test. We examined the Bomberos' Costa Rican fire statistics regarding causes of fires. We also visited buildings in order to observe common building materials. Once we determined a list of building materials, we narrowed it down by interviewing the Bomberos and UCR professors about the materials they wanted to test. In this section, we explain these research methods and the importance of the information we attained.

3.1.1 Fire Statistics Research

Since 2008, the Bomberos have maintained extensive records of fire statistics and fire related data, which they provided us. We examined these fire incident reports as well as annual reports regarding the number and causes of fires that occurred between January 2008 and September 2010. The annual reports presented the data in graph form (Appendix D.1), so we created a master table for easier overall analysis of the data from the past three years. Based on this information, we determined which materials would be most relevant to test in the laboratory. Furthermore, we used this information to establish possible fire hazards at the buildings we visited. Through analysis of these fire statistics, we established what kinds of materials will be most beneficial for our sponsors to test in the fire-testing laboratory; this information, in turn, informed our final recommendations.

3.1.2 Building Site Visits

We made site visits to Hospital de Heredia, Hospital San Juan de Dios and Hospital México to attain first-hand knowledge of building materials used in Costa Rica. Although there are other hospitals in or around San José, the Bomberos helped us choose these three hospitals because of their varying ages. Hospital de Heredia, which opened in August 2010, is the newest hospital in Costa Rica, while Hospital San Juan de Dios, the oldest, was established in 1845. Hospital México, between the previous two, was established in 1969. As a result, we observed the differences in building materials and fire safety precautions between the hospitals. We focused our visits on hospitals as opposed to other buildings due to the limited amount of time that we had. Since hospitals are public buildings, it was easy to access them and to attain a tour and informal interview with the engineer of the hospital.

During the three hospital visits, either Civil Engineer Esteban Ramos or Señor Jacinto Saborío (our liaisons from the Engineering Department of the Bomberos) accompanied us. They pointed out materials they would like the UCR laboratory to investigate, as well as fire safety precautions or fire hazards that were important for us to take note of. Our UCR liaisons, Mechanical Engineer Patricio Becerra and Chemical Engineer Marcela Shedden were also present for all three visits to point out materials they wanted to test. Additionally, they helped translate information from the hospital engineers because two out of the three tours were primarily in Spanish.

For our visits to Hospital de Heredia, Hospital San Juan de Dios and Hospital México our group met with the head engineer or an engineer of each hospital, who were Head Engineer Aldo Protti, Chief Engineer Jose San Francisco and Engineer Reinaldo M., respectively. We organized these visits with a hospital engineer to fully understand the materials used in the hospitals, as well as to obtain access to restricted areas such as laundry facilities, machinery rooms and storage areas. By visiting these rooms, we determined what materials could be tested to improve fire safety in the hospital. With each visit, we asked the engineers the following questions:

- What are the primary building materials of the hospital?
- What kinds of fire safety precautions/systems does the hospital have?
- Are there any potential fire hazards in the hospital?

As each engineer at each hospital explained the building materials used and the hospital's fire safety precautions (such as the availability of fire extinguishers and sprinkler systems), we noted what they said as well as our own observations of the hospitals. Furthermore, we collected visual data to support our notes by taking pictures of the possible materials our sponsors can test, fire safety precautions and possible fire hazards. With our sponsors, we also collected some small samples of materials from the hospitals that they can test with the Microscale Combustion Calorimeter that UCR already bought. This included lint from the Hospital México laundry area, a piece of the blanket that burned in the March 2010 fire incident in Hospital México, and sawdust from Hospital San Juan de Dios.

From the information we collected at these hospital visits we created a general list of materials that the laboratory at UCR can test. Even though this was the main goal of the building visits, our group also collected information regarding the hospitals' fire safety precautions. Fire safety is one of the main concerns of the Bomberos and learning about them through our building visits provided us with better understanding of the implications of our project.

3.1.3 Narrowing List of Testing Materials

After the three visits, we categorized the materials data we collected into two types of materials: construction materials and supplementary materials. Construction materials are those that are used for the structure itself, such as concrete and wood. Supplementary materials are those that are found visibly within and do not contribute to the structure of the building, such as bedding materials and plastic railings. We compiled this data into a master table for easier comparison of the common materials in all three hospitals. Since this list consisted of numerous kinds of materials, it was necessary to narrow it down by determining what materials were most important for both our sponsors. We interviewed Señor Saborío of the Bomberos to establish which materials were the Bomberos' highest priorities to test in the laboratory. We also interviewed Engineer Becerra and Engineer Shedden to determine which materials the UCR wanted to test as well. We compared the UCR's list to the Bomberos' list to determine the common materials both sponsors favored and created the final list of testing materials. This information influenced the pieces of equipment that we recommended, which we presented in Chapter 5.

3.2 Determining Which Courses the Laboratory Will Supplement

In order to recommend equipment to support UCR's FPE courses, we evaluated each course that UCR is implementing into the curriculum by using the course descriptions our sponsors provided (see Appendix E.1). From this analysis we chose which courses would best be supported by fire-testing equipment. This allowed us to narrow our research in terms of relevance of equipment.

3.3 Researching Equipment

In October 2010, Engineers and Professors Patricio Becerra and Marcela Shedden of UCR gave us a list and a packet of information regarding the equipment that they were interested in purchasing (see Appendix E.2). We devised a spreadsheet of the information using Microsoft Excel to guide and organize our research; it also served as a live document for tracking findings (see Appendix E.3). The primary task of this research was to evaluate each piece of equipment on this list and to understand its purpose in a fire-testing laboratory. To do this we utilized reliable Internet sources and interviewed professors from WPI who are knowledgeable in fire-testing. We also gathered information on size of the equipment, materials tested, fire properties tested, and ability to support UCR's FPE courses. The following section describes the specific methods we used in our research.

3.3.1 Determining Purpose of the Equipment

The most important facet of our equipment research was the purpose of each piece. Our sponsors from UCR want the recommended equipment to perform prescriptive-based tests because their mechanical engineering undergraduates do not have the chemical background necessary to operate performance-based equipment or analyze the results. Instead, the students will be using the equipment under the supervision of trained professors to partake in experiments that will supplement the material taught in the FPE courses. Consequently our sponsors also wanted the recommended equipment to support their FPE courses. The Bomberos want to use this fire-testing laboratory to test construction materials for fire properties. Testing these materials will help them understand fire reaction in real-scale fires and will therefore help them to better fight fires. When we investigated the purpose of the equipment, we used all of our sponsors' preferences to guide our research. We examined the ASTM and ISO standard test methods associated with each piece of equipment because they describe what materials and properties the equipment tests. We used <astm.org> and <iso.org> to understand the scope of each test method. When the standards did not provide substantial information, we investigated manufacturers' websites for the specified equipment. Specifically, we used the websites of The Govmark Organization Inc. and Fire Testing Technologies Ltd. With a strong understanding of the function and purpose of all of the equipment, as well as our sponsors' needs, we generated recommendations for UCR's fire-testing laboratory.

3.3.2 Determining Specifications of Equipment

We also examined the specifications of each piece of equipment to analyze whether or not it would fulfill our sponsors' needs. For each piece of equipment, we inspected the standards it supports, the materials it tests, the fire properties it tests for, and the FPE courses it supplements. We also investigated the size of equipment in order to devise a correct sketch of the laboratory. We found some of these specifications within the packet of information from our sponsors. We found other specifications using manufacturers' websites, such as The Govmark Organization Inc. and Fire Testing Technologies Ltd. These were the three manufacturers that sold the equipment on our list. When we could not find this information using the Internet, we emailed the respective companies as a potential buyer asking for the specifications of the equipment. We used the results of this research to complete both our qualitative and quantitative analyses explained in Section 3.4.

3.4 Developing Equipment Analysis Tools

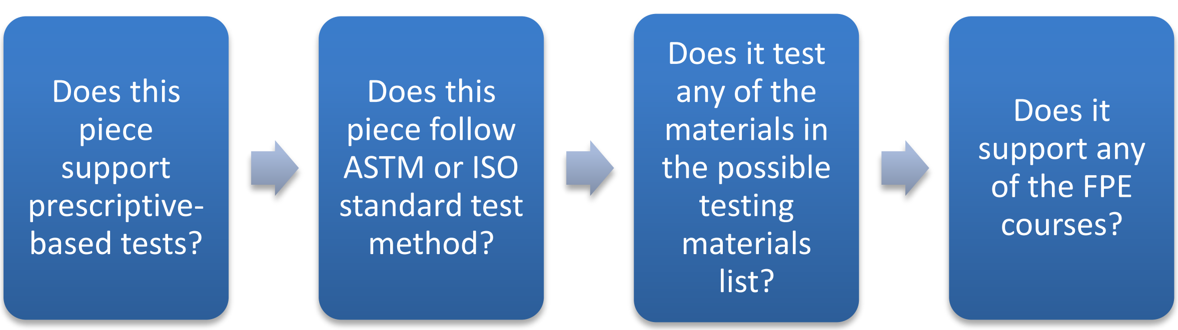
In order to determine the most relevant pieces of fire-testing equipment for this laboratory, we developed two different equipment analysis tools: qualitative and quantitative. We interviewed our sponsors to determine the most relevant factors to consider for these tools in an unbiased manner. We asked them to rank different equipment factors on a scale of 1-5 where a 1 was of lowest importance to consider when analyzing. The factors we presented to them were the type of tests, materials tested, fire properties tested, test standards used, relevance to FPE courses, price, sample size and size of equipment. Using the factors of highest priority in our tools, the qualitative tool eliminated equipment that was not relevant to our sponsors' needs, while the quantitative tool ranked the equipment by most relevant to least relevant. Through these tools we determined the five most relevant pieces of equipment to recommend.

3.4.1 Qualitative Analysis Tool

After we determined the different characteristics of each piece of equipment on the list, we developed a qualitative analysis tool to eliminate irrelevant equipment in preparation for the quantitative analysis. Our UCR sponsors wanted the recommended equipment to perform prescriptive-based tests, follow ASTM or ISO standards, and support their FPE classes. Our sponsors from the Bomberos wanted the recommended equipment to test the fire properties of the materials we determined from our research. Therefore, the criteria for our qualitative analysis tool (shown in Figure 2) included the following topics:

1. Prescriptive vs. performance testing
2. Standard test methods the equipment followed
3. Materials the equipment tested
4. Equipment's relation to FPE courses.

Figure 2: Flow Chart of Qualitative Analysis Tool



To organize our qualitative analysis data, we created a blank table using Microsoft Excel (see Table 2 on next page). This consists of the list of equipment, manufacturer of the equipment, the four criteria, and a “Final Outcome” column, in which we indicate whether the equipment passes or fails our analysis. Using our findings from equipment research, we analyzed each piece of equipment with our analysis tool, and answered each question with yes or no. If the answer was “no” to any question, we did not answer the proceeding questions and labeled the equipment as “eliminate” for its final outcome. Through this analysis, we were able to narrow down our list of equipment to those that were actually relevant to the laboratory’s needs. This enabled us to design a quantitative tool that ranked all of these pieces of equipment against each other to determine the top choices.

Table 2: Blank Qualitative Analysis Tool

PIECE OF EQUIPMENT	Manufacturer	Does this equipment support prescriptive tests?	Does it use ASTM or ISO standards?	Does it test materials on the list?	Does it support any FPE courses?	Designated Level (Pass or Eliminate)
Blanket Flammability Tester	Govmark					
Combustion Resistance	Fire Testing Technology Ltd					
Cone Calorimeter	Govmark					
Flammability Tester	Fire Testing Technology Ltd					
Flooring Radiant Panel Tester	Govmark					
Glow Wire Flammability Test	Fire Testing Technology Ltd					
Ignition Temperature	Fire Testing Technology Ltd					
Large Scale Flammability Tester (Model 701L)	Govmark					
Non Combustion for Building Materials	Fire Testing Technology Ltd					
OSU Rate of Heat Release Tester	Govmark					
Oxygen Index	Fire Testing Technology Ltd					
Protective Flammability Tester (Model TPP-2)	Govmark					
Radiant Panel	Fire Testing Technology Ltd					
Radiant Panel Flame Spread Tester	Govmark					
Silumdum Resistance	Fire Testing Technology Ltd					
Single Burning Item (SBI)	Fire Testing Technology Ltd					
Small Flame Reaction (mutiple setups)	Fire Testing Technology Ltd					
Small Scale Plastics Flammability Tester (Model GOV-94)	Govmark					
Smoke Density Tester	Govmark					
Flammability Tests (horizontal sample)	Fire Testing Technology Ltd					
Flammability Tests (vertical sample)	Fire Testing Technology Ltd					
Test assembly for flammability tests	Fire Testing Technology Ltd					
Vertical Flammability Tester (1)	Govmark					
Vertical Flammability Tester (2)	Govmark					

3.4.2 Quantitative Analysis Tool

We designed a quantitative analysis tool to determine the essential pieces of equipment for the needs of our sponsors. We developed a tool that is similar to the ranking system of *Car and Driver Magazine*. We used their examples as baselines for our table (see Appendix F.3).

We determined the different factors that distinguish the fire-testing equipment from each other. The equipment specifications research helped us to determine the different equipment factors which were:

- Number of fire courses the equipment would support
- Number of standard test methods the equipment supports
- Number of relevant materials that can be tested (determined by the material research)
- Number of fire properties that equipment measures
- Sample size the equipment tests
- Total price of the equipment
- Physical size of the equipment
- The accessories needed to purchase for full functionality for the equipment.

We interviewed Engineer Becerra and Engineer Shedden of UCR on 23 November 23, 2010 to understand what the importance of each factor for the equipment in the laboratory. This interview helped us to effectively recommend the equipment that best met their needs. We asked them to rank each factor on a scale of 1-5, where 5 was the most important factor to consider and 1 was the least. We only allowed Engineers Becerra and Shedden to use two of each number (they could only give two 5's, two 4's, two 3's, and so on) to make sure a variety of scores were given. We also gave them the opportunity to remove any of the factors that had no importance to them (see Appendix F.4).

With the results of the interview, we made the final tool for the quantitative analysis. We removed five of the nine factors from the analysis tool, by sponsor requests. The factors that they wanted us to rank for each piece of equipment, and the importance factor of each were as follows:

- Most Important (5)
    - Number of fire courses the equipment will supplement
    - Number of fire properties the equipment can test

- Important (4)
    - Number of relevant materials the equipment can test
    - Number of standard testing methods the equipment supports

Next, we assigned maximum values used to evaluate each factor. For the most important (5) factors we gave a maximum value of 25 points. For the important (4) factors we gave a maximum score of 20 points. Based upon these maximum point values, our group then designed a scoring rubric for completing the quantitative tool. This provided an unbiased approach to scoring the equipment. Future researchers can also follow this system to recreate or further develop our project. The blank quantitative analysis is tool is shown in Table 3 on the next page.

Table 3: Blank Quantitative Analysis Tool

PIECE OF EQUIPMENT	Manufacturer	Fire Courses	Standards	Materials	Fire Properties	FINAL TOTAL
Rating Description	-	# of courses equipment can supplement	# of standard test methods equipment supports	# of relevant materials that can be tested	# of fire properties equipment measures	-
Maximum Points	-	25	20	20	25	90
Blanket Flammability Tester	Govmark					0
Cone Calorimeter	Govmark					0
Flammability Tester	Fire Testing Technology Ltd					0
Flammability Tests (horizontal sample)	Fire Testing Technology Ltd					0
Flammability Tests (vertical sample)	Fire Testing Technology Ltd					0
Ignition Temperature	Govmark					0
Non Combustion for Building Materials	Fire Testing Technology Ltd					0
Radiant Panel	Fire Testing Technology Ltd					0
Radiant Panel Flame Spread Tester	Fire Testing Technology Ltd					0
Single Burning Item (SBI)	Govmark					0
Small Scale Plastics Flammability Tester (Model GOV-94)	Fire Testing Technology Ltd					0
Smoke Density Tester	Govmark					0
Test assembly for flammability tests	Fire Testing Technology Ltd					0

We created a rubric which we used to rank the equipment (see Figure 3). We used the following methods to create this rubric. In order to rank equipment in terms of relevance to the fire science courses at UCR, we considered the three courses that can be supplemented by fire-testing equipment: Risk Analysis, Chemistry for Fire Protection, and Fire Dynamics. The highest score for this category is 25 points. Equipment that can support only one course was lowest priority, so we gave it a score of 5 points. For each additional course (up to three) a piece of equipment would gain 10 more points. Equipment that can support all three was ranked highest at 25 points.

In order to rank equipment in terms of the standards it supports, we examined the equipment that passed the qualitative analysis. We found that the maximum number of standards executed by a single piece of equipment was 6 and the minimum was 1. Because the maximum score for this category was 20 points, we divided 20 by 6 and concluded that there should be between 3 and 4 points awarded for each supported standard. For example, equipment that supports only one standard received 3 points, two standards received 7 points, and so on. We used this same method to rank the number of fire properties tested by each piece of equipment. The maximum score for this category was 25. After examining the equipment, we found that the maximum number of fire properties tested by a single piece of equipment was 7 and the minimum was 1. Therefore, we divided 25 by 7 and found that there should be between 3 and 4 points awarded for each number of tested properties.

Figure 3: Quantitative Analysis Ranking Rubric

Fire Courses:
- 3 courses = 25 points
- 2 courses = 15 points
- 1 course = 5 points

Standards:
- 1 standard = 3 points
- 2 standards = 7 points
- 3 standards = 10 points
- 4 standards = 13 points
- 5 standards = 17 points
- 6 standards = 20 points

Fire Properties:
- 1 property = 3 points
- 2 properties = 6 points
- 3 properties = 10 points
- 4 properties = 13 points
- 5 properties = 17 points
- 6 properties = 21 points
- 7 properties = 25 points

Materials:
- 1 specific type of material= 3 points
- 1 specific category of material (i.e. plastics) = 7 points
- 2-3 types of materials = 10 points
- 4-6 types of materials = 17 points
- 1 general category of materials (i.e. building materials) = 15 points
- "All" = 20 points

We did not rank the equipment in terms of number of materials it can test purely by number. In some cases, equipment can test an entire category of materials. At minimum, a single piece of equipment can test the properties of one specific material (such as “blankets” or “rigid plastic specimens”). We gave these pieces of equipment a score of 3 points. For equipment that could test for one specific category of materials (such as “plastics” or “textiles”) we gave a score of 7 points. For equipment that can test for 2-3 different types of materials and 4-6 types of materials we gave scores of 10 and 17 points respectively. For equipment that can test for one general category of materials (such as “building materials” or “coating materials”) we gave a score of 15 points. Finally, we decided that equipment that can test all materials would receive the highest score of 20.We used this rubric to complete our quantitative analysis; the results of it directly influenced our recommendations.

3.5 Researching Laboratory Safety

The UCR sponsors wanted to include as many aspects of the proposed fire-testing laboratory as possible into our project, which included laboratory safety. We focused on the aspects that directly related to the fire-testing laboratory at UCR in San Pedro in order to maintain realistic goals. We researched NFPA and Inteco codes and standards to determine important safety features as Costa Rica has adopted these codes (Caledonia, 2005). We investigated active suppression systems such as automatic sprinklers and fire extinguishers. We also researched relevant supplementary safety features such as gas detectors and emergency showers and eye wash stations, which would help ensure a safe environment of the laboratory on a daily basis.

3.5.1 Active Fire Suppression Systems

We researched suppression systems such as automatic sprinkler systems and portable fire extinguishers for proper safety of the laboratory. For each type of preventative equipment, we compared specifications and purposes of all of the different models. We did not consider feasibility as a limitation per request from our UCR sponsors. As a result, we did not take the practicality of purchasing or installing the equipment into consideration. Instead, we concentrated on how the equipment would produce a safer work environment for the laboratory in adherence to NFPA codes.

We researched the basics of portable fire extinguishers. We used the website <FireExtinguishers101.com> to understand the different classifications of fires and how these different fires require different types of extinguishers. We also coordinated with the UCR sponsors to gain access to UCR library's Inteco standards. We used INTE 21-01-01-96, "Extintores portátiles contra el fuego (Portable Fire Extinguishers)," which referenced NFPA 10 "Portable Fire Extinguishers," and then cross referenced the information found in Inteco with the Bomberos' copy of NFPA 10. We concentrated on Chapter 5 of NFPA 10 which outlined the requirements for selection of portable fire extinguishers and also investigated the general requirements (Ch. 4) and installation (Ch. 6) of extinguishers.

After researching fire extinguishers, we investigated automatic sprinkler systems. We utilized similar research methods. We investigated online fire protection resources such as the Fire Protection Engineering Magazine <fpemag.com> and the National Fire Sprinkler Association <nfsa.org> in order to discover new trends in sprinkler technologies. We also read the Inteco standard for the different sprinkler types (INTE 21-01-04-96) and sprinkler risk categorization (INTE 21-01-05-02). Furthermore, we read NFPA 13 which is the "Standard for Installation of Sprinkler Systems." We examined chapter 8.4, which outlined the different applications and functions of different sprinkler systems. We focused on the specific roles and safety factors of the different categories because this was the most pertinent information for the selection of a proper system for the laboratory.

3.5.2 DAILY SAFETY NEEDS

We researched important reactionary safety equipment that the laboratory should have because guaranteeing safety on a daily basis is essential when conducting fire-tests. The main reactionary measure for laboratories were emergency eyewash stations and showers. They provide a method for washing chemicals out of eyes and off of the entire body. We first used the Stanford Laboratory Standard & Design Guide, which provided us with the basic information of eyewash and shower stations as well as referenced other sources to investigate. One of these sources was the Canadian Centre for Occupational Health and Safety. The site referenced the code ANSI (American National Standards Institute) Z358.1-2009 "Emergency Eyewash and Shower Equipment." We used this specific information to choose the type and location of the emergency eyewash and shower equipment for the laboratory.

We also researched gas monitors, which measure the level of dangerous gases in the atmosphere of a laboratory. We examined Inteco standards INTE 21-01-29-98, INTE 21-01-26-98, and INTE 21-02-01-97, which relate to automatic detection systems and alarms. We also looked at relevant NFPA standards, specifically numbers 72 and 720 which relate to automatic signals and carbon monoxide alarms. We followed these NFPA codes to recommend an adequate type of gas monitor to ensure a safe gaseous environment in the laboratory.

3.6 Determining Laboratory Layout

The final step of our project was to create a layout of the fire-testing laboratory at UCR San Pedro. We knew that UCR planned to remove all of the mechanical engineering equipment currently in the laboratory. Therefore, to account for maximum space, we measured all dimensions of the room, including the placement of permanent fixtures such as doors and windows. With these measurements, we used the Autodesk's Revit Architecture 2011 to generate a three-dimensional sketch of the empty UCR San Pedro laboratory, and then added our recommended equipment to the sketch. We considered functionality and necessary work space as well as NFPA, ANSI, and Inteco standards to determine the placement of the equipment. After revising the arrangement several times and ensuring we were adhering to the appropriate codes, we chose the best layout of the laboratory, which we present in Chapter 5.

4.0 Findings and Discussion

The goal of this project was to recommend pieces of equipment, safety precautions and a layout for the UCR San Pedro fire-testing laboratory. We focused on collecting and analyzing data regarding five topics:

- Testing materials
- FPE courses in UCR that can use laboratory equipment
- Laboratory Equipment Specifications
- Laboratory Safety Needs
- Dimensions of UCR San Pedro Laboratory.

We compared the materials we found at our three building visits to the Bomberos fire statistics in order to determine what materials our sponsors should test in their laboratory. We then analyzed course descriptions to find which FPE courses would benefit from fire-testing equipment. Based on these findings we used the analysis tools, determined in our methodology, to establish a final list of equipment. We also determined laboratory safety needs based upon these findings. Finally, we measured the dimensions of the UCR San Pedro laboratory to provide a layout of the laboratory. This chapter discusses the findings we obtained over the course of our project.

4.1 Materials Findings

We determined the top causes of fires in Costa Rica and established a list of building materials our sponsors should test in the UCR laboratory through the analyses of the Bomberos' statistical fire data and touring three public buildings. The list of materials was useful in completing our qualitative and quantitative analyses of the equipment list. This section describes our material findings.

4.1.1 Bomberos Fire Statistics

The Bomberos' fire statistics, organized in graphs, show the causes of fires in Costa Rica (see Appendix D.1). We organized this data from 2008-2010 into one master table for easier analysis, as shown in Table 4. Because of the large variety of fire causes, we focused on the top three. All others were categorized into "others". This table shows that in the past three years, electrical systems were the main cause of fires in Costa Rica. The Bomberos do not know how electrical systems are the primary causes of fires. Therefore, we determined that materials used

Table 4: Percentage of Fires Caused by Electric Systems, Electrical Apparatus, Arson and Other Materials in 2008-2010

Year	Total # of Investigated Fires	Percentage(%) of fires caused by:			
		Damaged Electric Systems	Damaged Electrical Apparatus	Arson	Others
2008	216	28	18	22	32
2009	92	27.3	18.7	15.6	38.4
2010	190	20	18	16	46

in electrical systems should be tested in the UCR laboratory to understand their properties and improve fire safety. This was the first material we included in our list of testing materials. Based on these findings, we noted any electrical systems at the buildings we visited because these could be potential fire hazards. We address these observations in the following sub-section.

4.1.2 Building Visits

Through the building visits to Hospital de Heredia, Hospital San Juan de Dios and Hospital México we determined a list of materials that were found in buildings. This included materials we found in different areas of the hospital such as the hallways, offices, laundry facilities and storage areas.

Hospital de Heredia is the newest hospital in Costa Rica and was built to satisfy NFPA codes. As a result, the hospital has installed proper fire safety measures such as sprinkler systems, fire extinguishers and 3-hr fire-resistant doors. Nonetheless, there are several types of materials that we determined to be of interest to engineers to test in a laboratory. One of these materials is Hospital de Heredia's plastic railings, shown in Figure 4. In a fire this material may release toxic chemicals and gases. Therefore, a toxicity test, performed with a sample of this material, would provide useful information to the Bomberos.

Figure 4: Plastic Railing in Hospital de Heredia

Similarly, they can also perform toxicity and fire-resistance tests on the material used in the suspended ceiling, shown in Figure 5. Furthermore, although their fire-resistant doors are certified to be 3-hr fire resistant, engineers can verify this claim once Costa Rica has a certification fire laboratory in the future. Through this visit, we determined a list of 19 materials that were used in this hospital (see Appendix D.2).

Figure 5: Suspended Ceiling of Hospital de Heredia

Hospital San Juan de Dios is the oldest hospital in Costa Rica, built in 1845, and was not built to satisfy NFPA codes. It does not have any fire protection systems; when we visited it on November 11, 2010, they were in the process of installing smoke detectors. Unlike Hospital de Heredia, which uses steel in its structure, Hospital San Juan de Dios is mainly constructed of concrete and wood. However, the hospital is trying to eliminate their wooden walls and is using metal in new construction. Electrical wirings in this hospital were also potential fire hazards because they were exposed. An example of these wirings is shown in Figure 6. One of the materials used in electrical wirings is polyvinyl chloride (PVC), which we included in our list of materials during this visit. This hospital has a laundry facility used by three hospitals. It has large machines for drying and ironing sheets that produce a large quantity of heat. We determined that the accumulation of lint and dust in the ceilings and floors, as shown in Figure 7, poses a potential fire hazard. Lint is highly flammable, and if a fire started in this area, flames could spread faster more easily through the lint. Therefore, our team together with our liaison, Engineer Marcela Shedden, collected some samples of the lint for testing in the UCR's Microscale Combustion Calorimeter. Another area that presented a fire hazard was their file room, which had numerous shelves filled with paper as

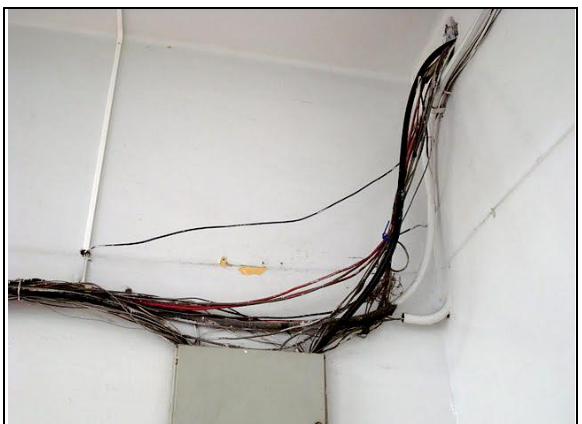


Figure 6: Exposed Wiring in Hospital San Juan de Dios

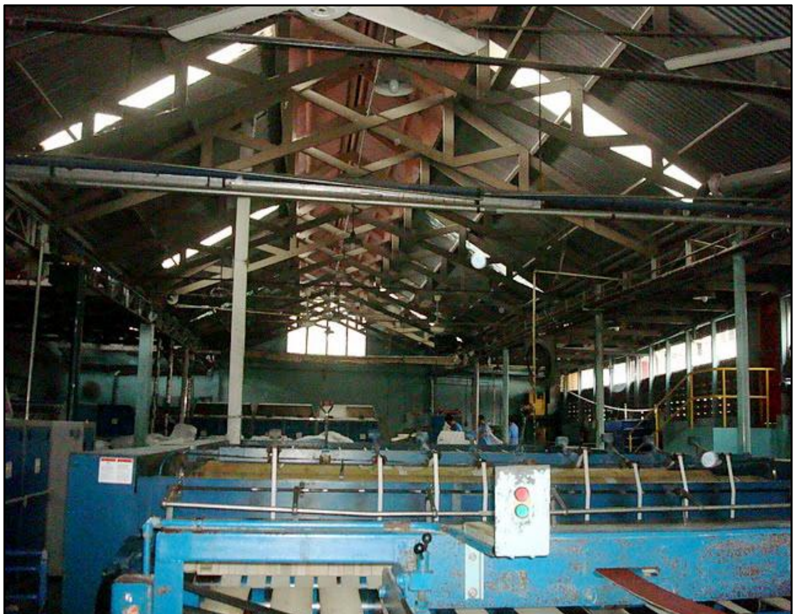


Figure 7: Ironing area in Hospital San Juan de Dios that had a lot of lint and dust on the ceilings and floors

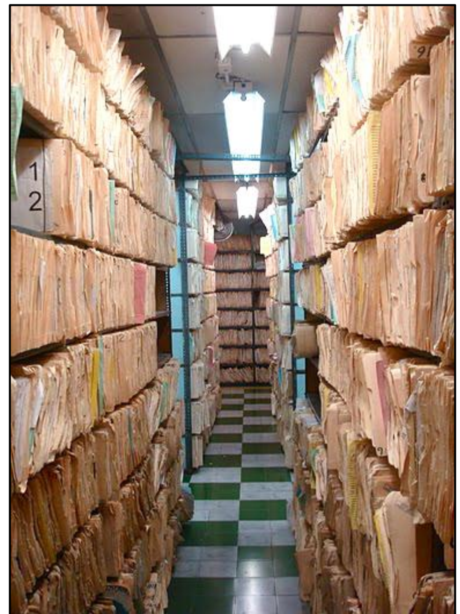


Figure 8: Patient Medical History Papers - Filing Area

shown in Figure 8. This was very close to the fluorescent ceiling lights, and from the Bomberos' statistics, we learned that damaged ballasts have caused fires in the past. Therefore, fire safety can be improved by studying how much heat is required to ignite paper.

Hospital México, established in 1969, is the largest national hospital in Costa Rica. It had many fire extinguishers and fire hoses, but did not have any sprinkler system. This hospital has a laundry facility that various hospitals in the country use to wash and dry sheets, uniforms and clothes. In January 2010, blankets self-ignited after they were dried and placed in a laundry basket. We obtained a sample of these blankets for testing with UCR's Microscale Combustion Calorimeter. We also collected samples of the sawdust, a fire hazard, which covered the surfaces of their workshop. Testing a material like this will allow the Bomberos to understand how dust will react with fire, and students can learn the fire properties of that sample wood. With this hospital visit, we established a list of 23 materials used in Hospital México (see Appendix D.2)

4.1.3 Final List of Materials

After all three visits, we organized the materials we found in each hospital into one table for comparison and categorized them into two types: construction materials and supplementary materials (see Appendix D.3). Based on these findings, we interviewed Señor Jacinto Saborío of the Bomberos on November 22, 2010 and Engineer Marcela Shedden and Engineer Patricio

Becerra of UCR on November 23, 2010 to learn which materials they wanted to test in the laboratory (see Appendix D.4). The ones that both sponsors favored became our final list of testing materials, which are:

- Bedding Materials
- Clothing Materials
- Curtain
- Drywall/Fibrolite
- Felt Cubicle Walls
- Gypsum
- Plastic
- Polyvinyl Chloride (PVC)
- Suspended Ceiling
- Wood

There are different kinds of equipment that test the fire properties of different materials, so the span of our recommended equipment should test most of the materials on this list.

4.2 FPE COURSES THAT USE FIRE-TESTING EQUIPMENT

By evaluating the course descriptions and using our background research of fire properties and equipment specifications, we determined that three out of the nine FPE courses were relevant to fire-testing equipment. Similar to our materials findings, these relevant course findings were necessary for completing Objective 4 of qualitatively and quantitatively analyzing the list of equipment. The relevant courses were Análisis de Riesgo (Risk Analysis), Química para Protección Contra Incendios (Chemistry for FPE) and Dinámica del Fuego (Fire Dynamics). The following section lists the courses that we both did and did not consider for our research and the reasons why.

4.2.1 COURSES THAT COULD USE THE LABORATORY

We considered "Analisis del Riesgo" (Risk Analysis) when researching equipment. While most of this course focuses on teaching students how to use qualitative and quantitative tools to analyze the risk of fire, there are still opportunities to use fire-testing equipment. The content of the course includes understanding consequences of toxic gas and vapors produced by fire and explosions of clouds of vapors. This course mainly teaches using lectures and case studies, but we think that fire-testing equipment that tests and explores toxicity will help supplement this course.

We considered "Química para Protección Contra Incendios" (Chemistry for FPE) when researching equipment because this course focuses on understanding the chemical reaction of fire. Students learn how to apply chemical concepts to the selection of construction materials that will reduce risk of fire. They also learn about the harmful chemical products that can be produced during a fire. This course teaches characteristics of fire such as the process of combustion, energy of a reaction, heat of combustion, heat of reaction, flammability and combustion efficiency. They also learn about materials such as combustible liquids and solids, construction materials or building contents such as hydrocarbons, plastics, and wood. This course will use lectures and investigations. Because there are many pieces of fire-testing equipment that test for the properties taught in this course, we determined that the equipment will efficiently supplement this course.

We considered "Dinámica del Fuego" (Fire Dynamics) when researching equipment. UCR has not implemented this course into their curriculum yet, but since the rest of the fire-science courses were based on University of Maryland's curriculum, we used their course description to understand the contents of Fire Dynamics. This course focuses on studying ignition, flammability, flame spread, and rate of burning of different materials. Through these studies, students will learn how to quantitatively predict combustion aspects and fire behavior of materials (University of Maryland: Department of Fire Protection Engineering, 2010). Because this course has scientific applications, and studies specific fire properties of materials, fire-testing equipment will be relevant to this course.

4.2.2 Courses that Could Not Use the Laboratory

We eliminated "Introducción a la Ingeniería de Protección Contra Incendios" (Introduction to FPE) because this course focuses on the student deciding if they would want to pursue FPE as a career path. It investigates the history of fire protection, the national context and implications of this area of study, and future perspectives. This course only uses lectures and conferences to teach the subject, and therefore using fire-testing equipment would not be applicable.

We eliminated “Segurdidad Humana” (Human and Life Safety) because this course teaches students how to apply NFPA’s Life Safety Code to different residential and public building situations. Students also learn how to use this code to design safety systems and emergency plans. Because this course primarily uses lectures, installation visits, investigations, and projects, we determined fire-testing equipment will not support this course.

We eliminated “Sistemas de Protección Contra Incendios 1” (Protection Systems Against Fire 1) because this course focuses on using water-based suppression systems to extinguish fire. This course teaches the reasons for using water-based systems and the components of and process of installing these suppression systems. Students investigate the physical and chemical characteristics as well as the economic aspects of water-based suppression systems. This course uses lectures, investigations, system visits, and calculation programs. Because the course focuses on the design and installation of suppression system, and not the actual testing of fire, we concluded that recommending fire-testing equipment for this course was not relevant.

We eliminated “Alarmas y Señales” (Alarms and Signals) because this course focuses on the criteria for the design, installation, and testing of fire detection systems. Students learn the importance of alarm systems for the prevention of fire. They also learn how to select, install, test, control and maintain these detection systems. While these systems could be tested in a laboratory, equipment for the testing of fire properties of materials, such as the ones we researched, are not relevant to this course.

We eliminated “Sistemas de Protección Contra Incendios 2” (Protection Systems Against Fire 2) because this course focuses on the design and installation of sprinkler systems for suppression. Students learn which systems are most prevalent in Costa Rica. They also learn about the components of the systems as well as the processes of selection, testing, operation, and maintenance of the sprinkler systems. A sprinkler system can be tested in a laboratory, but for the scope of our project (testing fire properties of materials) we will not be recommending fire-testing equipment that is relevant to this course.

We eliminated “Sistemas de Protección Contra Incendios 3” (Protection Systems Against Fire 3) because this course focuses on the use of gaseous and chemical based suppression systems and equipment. Students learn the reasons for using these systems and become familiar with the components of them. They also study the effects that using these systems has on the environment. This class uses lectures, investigations, and installation visits to teach the subject.

While these systems can be tested in a laboratory, the fire-testing equipment we recommend, which will test for fire properties of materials, will not be relevant to this course.

4.3 Fire-Testing Equipment Findings

We compiled all of our equipment specifications research into one Microsoft Excel spreadsheet. We used these specifications to complete both the qualitative and quantitative analyses tools that we designed. These tools enabled us to determine the most relevant pieces of equipment for the laboratory in an unbiased manner. Our sponsors, when analyzing new equipment in the future, can also use these tools to determine its relevance to their needs. We eliminated 11 pieces of equipment with the qualitative tool because they were not relevant to our sponsors needs for the laboratory. The quantitative tool ranked the remaining pieces of equipment using the scoring rubric we created. From this ranking we determined the five most relevant pieces of equipment for our final recommendations.

4.3.1 Equipment Purpose and Specifications

In order to analyze the pieces of equipment, we determined the different properties and specifications of each piece on the list. We used our background research, manufacturers' websites Govmark Inc. and Fire Testing Technology Ltd., the packet of equipment information our UCR liaison provide to us, and our FPE course findings to identify these characteristics.

Tables 5 and 6, on pages 39 and 40 respectively, contain all of the data we collected through our equipment research methods. The table is organized by:

- Manufacturer's name
- Indication if the piece of equipment performs fire tests or not
- Standard test method(s) it follows
- Indication if the piece of equipment is prescriptive-based or not
- Materials it tests
- Fire properties it measures
- Relevant UCR courses the equipment will supplement
- Number of accessories needed for operation
- Physical size
- Total price

It was necessary to organize this data in a spreadsheet for ease of comparison and use during the qualitative and quantitative analyses. The pieces of equipment highlighted in yellow are those that did not perform fire tests. Therefore, we did not identify their specifications and eliminated them from the list of pieces of equipment to be qualitatively analyzed. Those in grey are the pieces of equipment that UCR has already bought: a Microscale Combustion Calorimeter and a Smoke Chamber. We researched their specifications in order to eliminate other pieces of equipment that had the same function.

Table 5: Specifications of all the Pieces of Equipment on the UCR list

PIECE OF EQUIPMENT	Manufacturer	Does it perform fire tests?	Related Code or Standard	Prescriptive-based or performance-based	Fire Properties	Materials it can test	Relation to FPE courses
AKRON Saberjet Nozzles	Akron Brass	No	-	-	-	-	-
Assault Nozzles		No	-	-	-	-	-
Blanket Flammability Tester	Govmark	Yes	ASTM D 4151	Prescriptive	Ignitability	Blankets	Chemistry 2 for FPE, Fire Dynamics
Combustion Resistance	Fire Testing Technology Ltd	Yes	ISO 3795, DIN 75200	Prescriptive	Resistance to combustion	Parts located inside automotives	Chemistry 2 for FPE, Fire Dynamics
Cone Calorimeter	Govmark	Yes	ASTM E 1354, ASTM E 1740, ASTM E 1550, ASTM D 5485, ASTM D 6113, NFPA 271, NFPA 264, ISO 5660 Parts 1 and 2	Both	Ignitability, Smoke production (amount), Mass loss, Heat and Smoke release rates, Heat of Combustion, Average Specific Extinction Area	Plastics, composites, wood, laminates	Chemistry 2 for FPE, Fire Dynamics, Risk Analysis
Flammability Tester	Fire Testing Technology Ltd	Yes	ASTM D 635	Prescriptive	Rate of Burning	Rigid plastic specimens	Fire Dynamics
Flammability Tests (horizontal sample)	Fire Testing Technology Ltd	Yes	ASTM D1532, ASTM EI321-09, ASTM D 5025	Prescriptive	Flame resistance, Ignition, Flame Spread	Textiles and plastics	Chemistry 2 for FPE, Fire Dynamics
Flammability Tests (vertical sample)	Fire Testing Technology Ltd	Yes	ASTM D6413, ASTM D 5025	Prescriptive	Flame resistance, Ignition, Flame Spread	Textiles and plastics	Chemistry 2 for FPE, Fire Dynamics
Flooring Radiant Panel Tester	Govmark	Yes	ASTM E 648, NFPA 253, ISO 9239-1	Prescriptive	Critical radiant flux at flameout	Carpeting and flooring materials used in public buildings and public transportation, attic insulation	Fire Dynamics
Flow Test Equipment		No	-	-	-	-	-
Flue Gas Drawing System in View of Toxicity Tests	Fire Testing Technology Ltd	Yes	ASTM E-662	Performance	Flue gas drawing for gas-chromatographic analysis	Smoke	Risk Analysis
Gauges		No	-	-	-	-	-
Glow Wire Flammability Test	Fire Testing Technology Ltd	Yes	IEC 695.21, VDE 0471 2 1	Prescriptive	Flammability	Materials used for fabrication of electronic components	Chemistry 2 for FPE
Hose & Apparatus Test Equipment		No	-	-	-	-	-
Ignition Temperature	Fire Testing Technology Ltd	Yes	ASTM D 1929	Prescriptive	Ignition and self ignition temperature	Plastic Materials	Chemistry 2 for FPE, Fire Dynamics
Large Scale Flammability Tester (Model 701L)	Govmark	Yes	NFPA 701, UL 214, CAN/ULC S109	Prescriptive	Ignition resistance	Draperies, cubic curtains, outdoor products, banners	Fire Dynamics
Micro Combustion Calorimeter	BOUGHT	Yes		Prescriptive	Flammability, Fire Load, Ignition Temperature, Heat Release Rate, Flame Resistance	Plastics, wood, clothing, etc.	Chemistry 2 for FPE, Fire Dynamics
Non Combustion for Building Materials	Fire Testing Technology Ltd	Yes	ISO/DIS 1182.2	Prescriptive	Fire Reaction	Building Materials	Chemistry 2 for FPE
OSU Rate of Heat Release Tester	Govmark	Yes	FAR Part 25 Appendiz F Part IV, Boeing BSS 7322, Airbus AITM 2.0006	Performance	Heat Release Rate	Aircraft Interior Materials	Risk Analysis
Oxygen Index	Fire Testing Technology Ltd	Yes	ASTM D 2863, ISO 4589-2	Prescriptive	Oxygen Index	Measure the 02 and N2 in a gas mixture	None
Protective Flammability Tester	Govmark	Yes	EN ISO 1182, EN ISO 1716, EN ISO 11925-2	Both	Thermal performance properties when exposed to high heat source	Materials used in protective clothing	None
Radiant Panel	Fire Testing Technology Ltd	Yes	ISO TC 92	Prescriptive	Fire Reaction, Flammability	Coating materials for walls, floors, ceilings and furniture	Chemistry 2 for FPE, Fire Dynamics
Radiant Panel Flame Spread Tester	Govmark	Yes	ASTM E 162, ASTM D 3675	Prescriptive	Flame spread, Flammability	Textiles, plastics, foam and similar materials used in furnishings, building products and transportation materials	Chemistry 2 for FPE, Fire Dynamics
Silumdum Resistance	Fire Testing Technology Ltd	Yes	IEC 707	Prescrtiptive	Burning rate, Burning time, Extent of burning	Rigid plastics	Fire Dynamics
Single Burning Item (SBI)	Fire Testing Technology Ltd	Yes	EN ISO 1182, EN ISO 1716, EN ISO 11925-2	Both	Fire Reaction, Heat and Smoke Release Rate	Building materials (excluding flooring)	Chemistry 2 for FPE, Fire Dynamics
Small Flame Reaction (mutiple setups)	Fire Testing Technology Ltd	Yes	CSE RF, DIN, UNI, EN-ISO	Prescriptive	Fire Reaction	Materials normally used in furnishing and building	Chemistry 2 for FPE
Small Scale Plastics Flammability Tester (Model GOV-94)	Govmark	Yes	UL 94HB, UL 94HBF, UL 94HF, UL 94V, UL94 VTM, UL 945V, ISO 1210, IEC 60695-11-10, IEC 60695-16-20, ASTM D635, ASTM D3801	Prescriptive	Burning properties of plastic materials	Plastics	Fire Dynamics
Smoke Chamber	BOUGHT	Yes	NFPA 258-T-89, ANSI/ASTM E-662-93, BSS-18, BS 6401	Prescriptive	smoke density from combustion of plastics,	Plastics	Risk Analysis
Smoke Density Tester	Govmark	Yes	ASTM E 662, ASTM F 814, NFPA 258	Undetermined	Smoke measurements of burning materials, Specific optical density under flaming and non-flaming, used for extraction of toxic gas	Solid materials	Risk Analysis
Tachometers and Flow Test Equipment		No	-	-	-	-	-
Test assembly for flammability tests	Fire Testing Technology Ltd	Yes	UL 94	Prescriptive	Flammability	Plastics	-
Test Cabinet	Fire Testing Technology Ltd	No	-	-	-	-	-
Vertical Flammability Tester (2)	Govmark	Yes	FedStd. 191A, NFPA 1971 6-2, ASTM D 6413	Prescriptive	Ignition resistance	Aircraft and transportation materials, tents and protective clothing	Fire Dynamics
Vertical Flammability Tester (1)	Govmark	Yes	NFPA 701 (1989), CPAI 84, CAN/ULC S109, UL 214, CA TB 117 AI and B, CA Title 19, 16 CFR 1615 and 1616	Prescriptive	Ignition resistance	Draperies, cubicle curtains, children's sleepwear, upholstery foams and tents	Fire Dynamics

Table 6: Continued Specifications of all the Pieces of Equipment on the UCR list

PIECE OF EQUIPMENT	Number of Accessories Required	Size	Price
AKRON Saberjet Nozzles	-	-	-
Assault Nozzles	-	-	-
Blanket Flammability Tester	N/A	Bench Scale 15"x21"x9"	N/A
Combustion Resistance	N/A	Small-scale 460mmx220mmx388h	N/A
Cone Calorimeter	0	Bench-scale	$ 115,000.00
Flammability Tester	N/A	Small-scale 430mmx280mmx380	N/A
Flammability Tests (horizontal sample)	N/A	Bench-scale	$ 3,500.00
Flammability Tests (vertical sample)	N/A	Bench-scale	$ 3,500.00
Flooring Radiant Panel Tester	0	Bench-scale	N/A
Flow Test Equipment	-	-	-
Flue Gas Drawing System in View of Toxicity Tests	N/A		N/A
Gauges	-	-	-
Glow Wire Flammability Test	1	Small-scale 506mmx506mmx750mm	N/A
Hose & Apparatus Test Equipment	-	-	-
Ignition Temperature	N/A	Small-scale 500mmx300x500, 700mmx500x500	N/A
Large Scale Flammability Tester (Model 701L)	N/A	Bench scale 17"x98"x16"	N/A
Micro Combustion Calorimeter			
Non Combustion for Building Materials	3	Bench Scale	$ 25,829.00
OSU Rate of Heat Release Tester	N/A	Bench-scale 27"x61"x__	N/A
Oxygen Index	N/A	N/A	$ 18,138.00
Protective Flammability Tester	0	Small-scale 36"x_x17.5"	N/A
Radiant Panel	N/A	Bench Scale	$ 28,299.00
Radiant Panel Flame Spread Tester	1	Bench scale 34"x42"x72"	$ 25,500.00
Silumdum Resistance	0	Small-scale 360mmx380mmx550mm	N/A
Single Burning Item (SBI)	N/A	Bench-Scale 3mx3mx2.6m, minimum height of 4.5m	N/A
Small Flame Reaction (mutiple setups)	N/A	Small-scale 700mmx400x810h	N/A
Small Scale Plastics Flammability Tester (Model GOV-94)	0	Small-scale	N/A
Smoke Chamber	4 optional	Test chamber mm 1500x900x1200	$ 75,373.00
Smoke Density Tester	N/A	Bench Scale	$ 25,000.00
Tachometers and Flow Test Equipment	-	-	N/A
Test assembly for flammability tests	N/A	Small-scale 1500mm x 900mm x1200mm	$ 14,500.00
Test Cabinet	10	Small-scale 1850mmx1310x3000h	$ 13,000.00
Vertical Flammability Tester (2)	7	Small-scale 21"x16"x32"	$3,895 (Automatic) $4,595 (Non-Automatic)
Vertical Flammability Tester (1)	7	Small-scale 21"x16"x32"	N/A

Data regarding price and number of accessories was unavailable for many pieces on the list, and we depicted this in Table 6 as N/A. We contacted manufacturer's regarding this information, but did not receive a response. Because Engineer Becerra and Engineer Shedden ranked price, size, and number of accessories as the least important factors in recommending pieces of equipment (see Appendix F.4), lacking this data was acceptable. This spreadsheet enabled our team to proceed in completing our qualitative and quantitative analyses.

4.3.2 Qualitative Analysis and Quantitative Analysis Findings

The qualitative analysis served the purpose of eliminating pieces of equipment that were not relevant to our sponsors' needs. We referred to the equipment specifications spreadsheet found in the previous sub-section, to complete this analysis (see Appendix F.2). Seventeen pieces of equipment passed the qualitative analysis because they fulfilled each of the four criteria: 1) runs prescriptive-based tests 2) supports UCR's FPE courses 3) follows ASTM or ISO standards and 4) tests the materials listed in section 4.1.3. This list was shown in Table 3 in section 3.4.2 of our methodology.

After completing the qualitative analysis and narrowing down the equipment list, we conducted the quantitative analysis and ranked the remaining pieces of equipment. We used the scoring rubric, described in our methodology, and referred to the equipment specifications spreadsheet, shown in Table 5 on page 39, to complete this analysis. Table 7, on the next page, shows the completed analysis, including the total scores and category breakdown of each piece of equipment.

Table 7: Completed Quantitative Analysis Tool

PIECE OF EQUIPMENT	Manufacturer	Fire Courses	Standards	Materials	Fire Properties	FINAL TOTAL
Rating Description	-	# of courses equipment can supplement	# of standard test methods equipment supports	# of relevant materials that can be tested	# of fire properties equipment measures	-
Maximum Points	-	25	20	20	25	90
Cone Calorimeter	Govmark	25	20	17	25	87
Single Burning Item (SBI)	Govmark	15	10	15	10	50
Radiant Panel Flame Spread Tester	Fire Testing Technology Ltd	15	7	17	6	45
Radiant Panel	Fire Testing Technology Ltd	15	3	15	6	39
Flammability Tests (horizontal sample)	Fire Testing Technology Ltd	15	3	10	10	38
Flammability Tests (vertical sample)	Fire Testing Technology Ltd	15	3	10	10	38
Non Combustion for Building Materials	Fire Testing Technology Ltd	15	3	15	3	36
Smoke Density Tester	Govmark	5	2	20	6	33
Ignition Temperature	Govmark	15	3	7	6	31
Small Scale Plastics Flammability Tester (Model GOV-94)	Fire Testing Technology Ltd	5	10	7	3	25
Blanket Flammability Tester	Govmark	15	3	3	3	24
Flammability Tester	Fire Testing Technology Ltd	5	3	3	3	14

Due to the explicitness of the grading rubric, the final results of the quantitative analysis provided a distinct ranking of the equipment. We listed the equipment from highest to lowest scores. We eliminated the Radiant Panel from Fire Testing Technology Ltd. from the final ranking because it performs the same tests as the Radiant Panel Flame Spread Tester from Govmark, which had a higher score. We indicated the equipment that we removed from the final rankings with "eliminate" in the Ranking category. We also eliminated the Smoke Density Tester, since this performs the same tests as the Smoke Chamber that UCR bought. From this analysis and ranking, we extracted the six pieces of equipment with the highest rankings to recommend to our sponsors. Table 7 shows that these are the Cone Calorimeter, Single Burning Item (SBI), Radiant Panel Flame Spread Tester, Flammability Tester (horizontal and vertical sample), and Non-Combustion Flammability.

As shown in Table 7, the Cone Calorimeter achieved the highest score in our quantitative analysis. It is the only piece on our list that supplements all three of the UCR fire science courses with laboratory components: Fire Dynamics, Chemistry for FPE, and Risk Analysis. It also measures the most fire properties of all the analyzed equipment: ignitability, smoke production, mass loss, heat release rate, smoke release rate, heat of combustion, and average specific extinction area. Additionally, it supports one ISO and five ASTM standard test methods, ranking it highest in that category. Lastly, the Cone Calorimeter tests a wide variety of materials, including plastics, wood, composites, laminates and small samples of building materials and upholstered furniture.

SBI ranked second in the quantitative analysis. It supplements UCR's Chemistry for FPE and Fire Dynamics courses. This piece of equipment also follows three ISO standards, tests building materials (excluding flooring) and tests for three fire properties: fire reaction, heat release rate, and smoke release rate.

The Radiant Panel Flame Spread Tester ranked third in our quantitative analysis. It supplements UCR's Chemistry for FPE and Fire Dynamics courses, supports two ASTM standard test methods, and tests many of our sponsors' desired materials, including textiles, foam, building products and plastics. This piece performs flammability and flame spread tests, making it appropriate for prescriptive based testing.

The Flammability Testers received the same score and both ranked fourth in our quantitative analysis. They supplement UCR's Chemistry for FPE and Fire Dynamics courses.

Each follows an ASTM standard test method and both measure ignition and flame spread of plastics and textiles. Because these two pieces of equipment can be installed in a single apparatus, we will further refer to them as one piece of equipment. The only difference between them is that one tests for vertical flame spread while the other tests for horizontal flame spread.

The Non-Combustion Flammability Tester ranked fifth in our quantitative analysis. Although it only follows one ISO standard, this piece of equipment tests all building materials, our sponsors' main priority. Accordingly, it attained the highest score for the materials category compared to other pieces of equipment. It tests for fire reaction and whether a material does or does not contribute to a fire without actual combustion. Therefore, this piece of equipment can supplement the Chemistry for FPE course.

4.4 LABORATORY SAFETY FINDINGS

We compiled and interpreted the information from our safety research to discover important trends. We found important information regarding active fire suppression systems and other safety equipment. These findings played a strong role in recommending safety equipment and the laboratory layout.

4.4.1 DETERMINING ACTIVE FIRE SUPPRESSION SYSTEMS

Our research on safety precautions indicated that NFPA standards require active fire suppression for the UCR laboratory. It also explained when active suppression systems are necessary, how to select appropriate models, and the installation standards of both portable fire extinguishers and automatic sprinkler systems.

Fire Extinguishers

There are five main categories of fire extinguishers. Table 8 shows the different classifications of fires, examples of materials, and the agents that extinguishers can use for each type of fire risk. According to NFPA 10 chapter 5.2, Type A fires involve conventional

Table 8: Findings for Different Classifications of Fire Extinguishers

Class	Fire Type	Material Examples	Possible Agents
A	Conventional Materials	Wood, paper	Air-Pressurized Water (APW), dry chemicals
B	Oil-based liquids	Gasoline, kerosene	Carbon Dioxide, dry chemicals
C	Electrical sources	Computers, wiring	Carbon Dioxide, dry chemicals
D	Combustible metals	Potassium, Magnesium	Dry powders (Sodium Chloride)
K	Cooking oils	Soybean oil, vegetable oil	Wet chemical (Potassium acetate)

combustibles such as wood or paper while Type B fires involve combustible liquids. Type C fires encompass electrical fires, Type D combustible metals such as magnesium, and Type K industrial kitchen fires including fried oil combustibles (NFPA 10, 2007, Fire-Extinguisher 101, 2010).

Table 9: Advantages and Disadvantages of Different Types of Fire Extinguishers

A	Air Pressurized Water (APW)	Powerful	Dangerous for any other fire class
ABC	Dry chemical	Powerful	Sticky residue, destroys electronics
BC	Dry chemical	Powerful	Corrosive residue, destroys electronics
BC	Carbon Dioxide	No residue	Weaker than dry chemicals
D	Dry powder	Powerful	Only applicable to Type D
K	Wet chemical	Powerful	Only applicable to Type K

Fire extinguishers can cover one or many of these classifications. Table 9 shows the most common types of extinguishers or extinguisher combinations, the agents they use, and the advantages and disadvantages for each. Air-pressurized water (APW) extinguishers are only designed for class A fires. APW extinguishers are very powerful against conventional materials but are ineffective or dangerous if used for any other fire class. Combinations ABC and BC extinguishers use dry chemicals, which leave behind a sticky residue that is difficult to clean. Carbon Dioxide extinguishers are designed for types B and C fires. They do not leave behind any residue after use and are therefore safe to use on electrical equipment (NFPA 10, 2007, Fire-Extinguisher 101, 2010).

NFPA 10 section 5.4.2.1 states that class A extinguishers are necessary for all structures (NFPA 10, 2007). Therefore the UCR laboratory is required to have a class A extinguisher. Combustible liquids and oil-based materials may be present in the UCR laboratory, posing the need for a class B extinguisher. Because there are electrical components in the fire-testing equipment, the laboratory requires a class C extinguisher as well. Neither combustible metals nor cooking oils will be used in the laboratory and, therefore, class D and K extinguishers are not applicable for the laboratory.

NFPA 10 also provides information for the selection of fire extinguishers. It distinguishes between the strengths of fire extinguishers based on number systems (NFPA 10, 2007). Section 5.3 of NFPA 10 states that only classes A and B extinguishers need numbers indicating their strength. Extinguishers classified as C, D, and K do not require a strength classification (Fire Extinguisher 101). Tables 10 and 11, on the next page, exhibit the strength requirements for classes A and B extinguishers. These tables also list additional requirements, such as the maximum allowable distance to travel to the fire extinguisher in an emergency.

Table 10: Fire Extinguisher Strength Requirements for Class A (NFPA 10)

Criteria	Low	Moderate	High
Minimum classification of extinguisher	2-A	2-A	4-A
Maximum Area per unit of A (m^2)	278.71	139.35	92.90
Maximum distance to travel (m)	22.70	22.70	22.70

Table 11: Fire Extinguisher Strength Requirements for Class B (NFPA 10)

Risk	Minimum Classification	Maximum distance to travel (m)
Low	5B	9.15
	10B	15.25
Moderate	10B	9.15
	20B	15.25
High	40B	9.15
	80B	15.25

According to NFPA 10, the fire-testing laboratory will be a moderate risk area due to the amount of flammable material present and frequency of heat emission. Table 12, below, shows the relationship between the different risk classifications based on NFPA 10 chapter 5.4 (NFPA 10, 2007). These risk classifications only apply to portable fire extinguishers and are not official building classifications, which the NFPA Life Safety Code 101 covers (NFPA 10, 2007). The equipment in the laboratory will emit heat during fire tests. However, faculty and students will only be using the equipment for relatively short periods of time. Additionally, the laboratory may have combustible liquids present in order to conduct certain tests. Although the volumes of combustible liquids may be less than 3.9 liters, the frequency of heat released by the equipment places this fire-testing laboratory in the moderate risk category.

Table 12: NFPA 10 Risk Classification for Fire Extinguishers

	Risk Classification		
	Low Risk	Moderate Risk	High Risk
Combustible Liquid Present (L)	Under 3.9	3.9-18.9	Over 18.9
Frequency of Heat Release	Low	Occassional	High

This moderate risk classification requires that the UCR San Pedro laboratory follow the moderate risk criteria for class A and B fire extinguishers. This also impacts the required strength of the laboratory's fire extinguishers. Based on this classification, Tables 10 and 11 indicate that the laboratory requires at least one extinguisher that has a strength rating of at least 2-A and 10-B. Our research also indicated that the laboratory should have an extinguisher that covers class C fires.

Sprinkler Systems

The Automatic Sprinkler Systems Handbook states, “Where sprinklers are present, the chances of dying in a fire are reduced by half or three-quarters, and the average property loss per fire is cut by one-half to two-thirds compared to fires, where sprinklers are not present” (Dubay, 2007). Our research indicated that a sprinkler system would foster a safer working environment for the UCR San Pedro fire-testing laboratory.

Table 13: Types of Sprinkler Systems According to NFPA 13

Sprinkler Type	NFPA Chapter and Section
Sidewall Spray	8.4.1
Extender Coverage	8.4.2
Open	8.4.3
Residential	8.4.4
Early Suppression Fast-Resonse	8.4.5
Large Drop	8.4.6
Special	8.4.7
Specific Application Control Made	8.4.8
Dry	8.4.9

There are numerous options for automatic sprinkler systems. Table 13 lists the sprinkler system types and sections of NFPA 13 that contain their specifications. There are benefits and drawbacks to each sprinkler system. There were many systems that are not feasible for this laboratory, such as extended coverage, open, residential, and dry sprinklers. These sprinklers had very specific functions that did not apply to a single room fire-testing laboratory. For instance, dry sprinklers are designed for “when sprinklers must be located in areas exposed to freezing conditions” (Dubay 2007).

In NFPA 13 we found that standard pendent and upright sprinklers and early suppression fast-response (ESFR) sprinklers were the two primary candidates for the fire-testing laboratory. ESFR sprinklers require less heat to activate, decreasing the reaction time and increasing survivability rates within the room. Pendent and upright sprinklers are standard sprinkler heads that do not have a heightened sensitivity. Their design prevents the spread of fire outside the room of origin (Isman, 2005; NFSA, 2010).

Based on our research, we concluded that pendent or upright sprinkler systems would be the best option for the fire-testing laboratory. ESFR sprinklers could potentially be set off accidentally due to the heat emitted by fire testing equipment. Although we were unable to discover the precise temperature emitted by fire-testing equipment, we understand that an accidental discharge would potentially destroy thousands of dollars of fire-testing equipment.

4.4.2 Determining Daily Safety Needs

A gas monitor is necessary for this fire-testing laboratory. Although we were unable to access NFPA 72 and 720, which detail fire alarms, signals, and carbon monoxide monitors, we found that combustion produces harmful gases such as carbon dioxide and carbon monoxide. Therefore, appropriate gas monitors will prevent dangerous levels of these gases and are essential in the laboratory.

Emergency eyewash and shower stations remove chemicals from the body after accidental exposure. ANSI Z358.1 "Emergency Eyewash and Shower Equipment" states that laboratories should select permanent combination emergency eyewash and shower stations before choosing portable stations. It also describes the selection and installation requirements for these stations. The UCR San Pedro laboratory should install a combination emergency eyewash and shower station in accordance with ANSI Z358.1 (CCOHS, 2010).

4.5 Determining Laboratory Layout

After measuring the dimensions of the mechanical engineering laboratory, we constructed the Revit Architecture model of the room. Figures 9, 10, and 11, on the next page are three-dimensional rendered images of the southeast, northwest, and southwest corners of the empty room. The room measures approximately 7.18m by 7.31m with a ceiling height of 2.93m. Due to space limitations, fire testing equipment should be placed in an organized manner along the north and west walls. According to NFPA 10, UCR officials should install the fire extinguishers away from all obstructions and mount them correctly on a wall (NFPA 10, 2007). Our sponsors stated that they would place the analytical scale in the small office space in the southeast corner. Therefore, the only available space for the fire-testing equipment is outside of the office.

All of the findings proposed in this chapter, including materials, courses, equipment, safety, and layout, directly impacted our recommendations. These recommendations are explained in the following chapter.

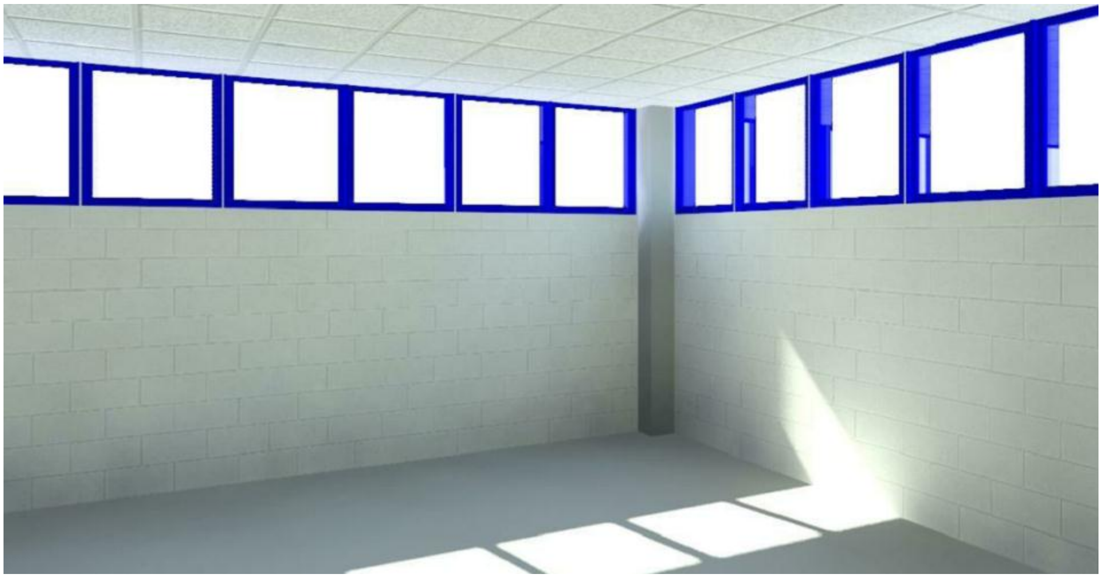


Figure 7: Northwest Corner for the Laboratory Layout

Figure 8: Southeast Corner for the Laboratory Layout

Figure 9: Southwest Corner for Laboratory Layout

5.0 CONCLUSIONS AND RECOMMENDATIONS

Based on the results of the qualitative and quantitative analyses, which used the needs of UCR and the Bomberos as criteria to prioritize a list of equipment, we recommended five pieces of equipment for the fire-testing laboratory. We also proposed appropriate laboratory safety precautions. With these equipment and safety recommendations in mind, we created a layout of the fire-testing laboratory using computer software. In this chapter, we presented the reasoning, limitations and implications of our recommendations. Furthermore, our team addressed opportunities for future development of this project.

5.1 EQUIPMENT RECOMMENDATIONS

Quantitative analysis proved the most important tool in determining the five most relevant pieces of equipment for the fire-testing laboratory because it ranked the equipment based on the needs of the Bomberos and UCR. There exists some overlap in the courses that the equipment supplements, the materials it tests, and the properties it measures, but each piece differs from the next in the combination of these factors. From these results, we recommend that UCR buy the following pieces of equipment for the laboratory:

Cone Calorimeter from The Govmark Corporation

The Cone Calorimeter ranked highest in our quantitative analysis (for justification see section 4.3.2). In support of our analysis, WPI FPE faculty members Randall Harris and Nicolas Dembsey stated in our interviews that the Cone Calorimeter is an essential piece of equipment in any fire-testing laboratory. Furthermore, our case studies showcased the cone calorimeter as the only fire-testing equipment that was present in all of the laboratories at the University of Canterbury, the University of Maryland, and Worcester Polytechnic Institute. However, due to its larger size, heavy weight, and extremely high price we recommend that our sponsors purchase the Cone Calorimeter only for the Alajuela laboratory in 4 to 5 years. This will ensure safer shipping and more space to accommodate this equipment.

With the Cone Calorimeter, researchers will be able to test many different properties of materials, as outlined in section 4.3.2 of the Findings and Discussions chapter. They will be able to calculate how long a specimen will take to ignite and how long it will burn for. Additionally, they will observe how the specimen reacts with fire and the byproducts it emits during combustion.

Single Burning Item (SBI) from Fire Testing Technology Ltd.

The SBI ranked second in our quantitative analysis (for justification see section 4.3.2). It is also the most commonly used equipment in Europe for testing and classifying construction materials. Therefore, it can be utilized in the proposed certification laboratory in the future. Because the SBI requires a minimum space of 3m x 3m x 2.6m and a minimum ceiling height of 4.5m, the San Pedro laboratory, with a ceiling height of 2.93m, cannot accommodate it. Therefore, we recommend that UCR purchase it in 4-5 years for the Alajuela laboratory, as well as to consider these dimensions during construction of the Alajuela laboratory.

The SBI will be very useful to the users of the laboratory because they will observe how construction materials react with fire. They will ignite a larger specimen of material and observe its behavior, including how fast the flame spreads, how long it burns for, and how much smoke it produces.

Radiant Panel Flame Spread Tester from The Govmark Corporation Inc.

The Radiant Panel Flame Spread Tester ranked third in our quantitative analysis (for justification see section 4.3.2). Additionally, because the Radiant Panel Flame Spread Tester supports the UL94 standard, which tests and certifies plastics to different levels of flammability, our sponsors can use this piece of equipment in 4 to 5 years as part of the planned certification laboratory at Alajuela.

This piece of equipment will allow researchers to observe the manner in which flame will spread, including the time it takes to ignite, and the speed and distance that the flame grows. It is different than other pieces that test for flame spread because it uses radiant heat as an ignition source instead of a direct flame, enabling researchers to understand the effects of heat alone and how high temperatures can start and contribute to fires.

Vertical and Horizontal Flammability Testers from Fire Testing Technologies Ltd.

The Flammability Testers ranked fourth in our quantitative analysis (for justification see section 4.3.2 of the Findings and Discussions chapter). With this piece of equipment, researchers will observe ignition and how flame spreads and reacts with materials when exposed to a direct flame. It tests parts in electrical devices and appliances, which are the main cause of fire in Costa Rica and are thus important for our sponsors to understand.

Non-Combustion Flammability Tester from Fire Testing Technologies Ltd.

The Non-Combustion Flammability Tester ranked fifth in our quantitative analysis (for justification see section 4.3.2). This piece of equipment will enable the user to test how readily a material will ignite using a radiant heat source. This information can help prevent incidents such as the hospital blanket fire, which ignited without a flame source.

5.2 Safety Recommendations

After researching safety measures and standards, we analyzed the laboratory's safety situation. Based on the recommended equipment and applicable NFPA, Inteco, or ANSI standards and codes, we recommend the following safety precautions for UCR to implement:

Develop or adopt, and then strictly adhere to, laboratory standard operating procedures (SOPs) as the primary preventative measure against injuries and accidents

Although safety precautions such as sprinkler systems can prevent accidents, the most important safety measure of this laboratory relies on the users following proper operating procedures. Every experiment in a fire-testing laboratory requires human interaction and involves the potential for human error. As an educational laboratory, undergraduate students will have access to sensitive and potentially dangerous equipment. Each piece of equipment should have its own SOP to ensure a safe laboratory environment. The UCR sponsors have already begun developing these for the Micro Combustion Calorimeter, and we recommend that they create SOPs for all of the equipment in the laboratory before allowing students to operate it.

Purchase and install type 2-A, 20-B and C fire extinguishers in adherence to NFPA 10, specifically one carbon dioxide extinguisher rated for type B and C fires and one dry chemical extinguisher rated for types A, B, and C

Based on NFPA standards and due to the types of combustible materials present, we classified this fire-testing laboratory as a moderate risk area in terms of fire extinguisher use. A carbon dioxide extinguisher is necessary in the event that a combustible liquid based or electrical fire occurs because it will cause the least amount of damage to the fire-testing equipment. A dry chemical extinguisher is also necessary in the event of a Type A (conventional combustibles) fire because the carbon dioxide extinguisher does not fight these fires. We concluded that Type D (volatile metals) and Type K (cooking oils) fire risks are not applicable to this laboratory, and therefore these types of extinguishers are unnecessary. All laboratory users should be familiar with the function and operation of these fire extinguishers to prevent misuse in an emergency. Finally, the UCR should adhere to all of the installation requirements mentioned in chapters 4 (General Requirements) and 6 (Portable Extinguisher Installation) of NFPA 10.

Purchase and install a standard pendent wet automatic sprinkler system in the laboratory in adherence to NFPA 13

We determined that a standard reaction sprinkler system would be the most suitable for a fire-testing laboratory. More temperature-sensitive systems such as quick reaction, early suppression fast-response (ESFR), and standard fast-response sprinkler systems would not be suitable for fire testing in which ambient heat transfer will cause high temperatures within the laboratory. The risk of a false alarm, which would potentially damage expensive fire-testing equipment, is too high with these systems.

We chose a pendent standard reaction sprinkler system because it does not have any stipulations. Section 8.4.1.1 of NFPA 13 permits the use of pendent systems in “all occupancy hazard classifications and building types” (NFPA 13, 2007). Other systems such as sidewall spray sprinklers and extended coverage sprinklers have limitations on their installation methods and performance. We also decided to use a wet system because, due to the climate of Costa Rica, there is no need to be concerned with freezing pipes that would cause failed systems. Therefore, a dry system would only hinder the effective response time of the sprinklers in the case of an emergency.

Purchase and install an appropriate gas monitor in accordance with NFPA 72 and 720

The UCR fire-testing laboratory needs an automatic gas detector to monitor the level of dangerous gases in the room’s atmosphere. UCR should search for the best candidate based on price limitations. Moreover, the choice should comply with the respective NFPA and Inteco standards. Installation, maintenance, and testing of the detector should adhere to the respective codes as well.

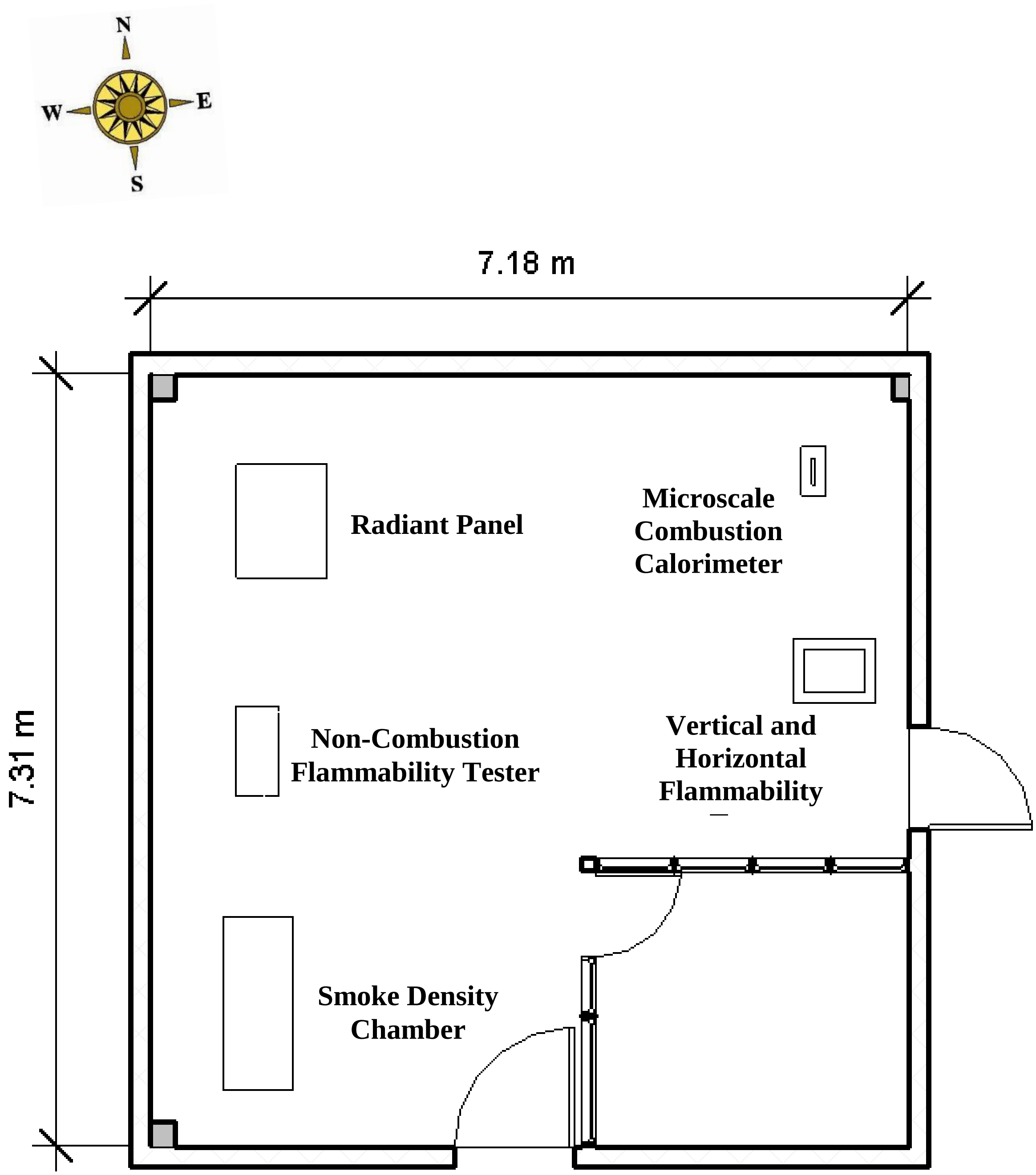
Purchase and install an emergency eyewash and shower combination station in accordance with ANSI Z358.1

An emergency eyewash and shower station is necessary for the fire-testing laboratory because testing samples can produce dangerous chemicals or gases that can cause injuries, such as burns. UCR should purchase a combination station, which contains both the shower and eyewash stations, to conserve space in the laboratory and eliminate the need for a sink. The installation of this station should adhere to all of ANSI Z358.1 requirements. UCR should pay special attention to the pressure levels of the shower and eyewash stations to ensure safe operating levels in case of an emergency.

5.3 Laboratory Layout Recommendations

We took into account space limitations of the current San Pedro laboratory in making recommendations for equipment and laboratory layout. We determined the most suitable equipment to be the Radiant Panel Flame Spread Tester, Vertical and Horizontal Flammability Tester, and Non-Combustion Flammability Tester. As stated before, the Cone Calorimeter and Single Burning Item Test are too large for the existing San Pedro laboratory. In addition, UCR has already bought a Micro Combustion Calorimeter and a Smoke Chamber, which we included in our layout of the laboratory. We considered the sizes of all these equipment, as well as the dimensions of the laboratory, to determine the most suitable layout. We used Autodesk's Revit Architecture 2011 to produce a two-dimensional object-oriented drawing of this layout as shown in Figure 12 on the next page. The software creates a dynamic drawing, so we were able to rearrange the design as many times as needed to produce the best layout.

Figure 10: Final Recommendation for Laboratory Layout



5.4 Recommendations for Future Expansion

We also recommended further development of this fire-testing laboratory. These recommendations, presented in this section, will help the Bomberos and UCR expand their fire-testing laboratory and create an accredited and respected Fire Protection Engineering program.

We recommend that contractors follow NFPA and Inteco codes when designing and constructing the fire-testing laboratory in Alajuela.

As described in Chapter 2, UCR will expand in Alajuela and create a new, larger fire-testing laboratory on this new campus. During construction of the laboratory, the contractors and architects should abide by NFPA 5000: Building Construction and Safety Code, which provides information regarding material choices, structural design, fire protections systems, and much more. The contractors should also comply with NFPA 13: Installation of Sprinkler Systems, which outlines the design, installation, supplies and equipment required for sprinkler systems. Taking these measures will assure a high level of safety in the new fire-testing laboratory.

We recommend that our sponsors adjust the budget for the Alajuela fire-testing laboratory to include maintenance and staffing.

Due to maintenance needs of a fire-testing laboratory, we recommend that our sponsors revisit the financial impact of the laboratory and devise a new budget. Fire-testing equipment requires constant maintenance, which UCR should allocate money for. Some equipment requires a recurring supply of materials for operation. For instance, the Cone Calorimeter has filtration aggregate that must be replaced depending on the frequency of its use (Randall Harris, personal communication, September 17, 2010). The budget needs to allow for equipment repair and replacement parts. UCR should also hire a full-time laboratory technician. As Professor Dembsey stated, it is essential to have staff members whose primary job is to ensure proper operation of the laboratory. At WPI, these personnel range from an associate professor who supervises the laboratory to a laboratory technician primarily responsible for operation of the laboratory (Nicholas Dembsey, personal communication, September 20, 2010). Staffing plays a vital role in the setup of fire laboratories, as staff will be learning all of the methods and procedures of a fire-testing laboratory. Therefore, the FPE budget must include the salaries for these personnel.

5.5 Further Implications of the UCR Fire-Testing Laboratory

The UCR laboratory will be the first fire-testing laboratory in Costa Rica, which has greater implications than only testing fire properties of construction materials. As UCR students use the laboratory they will have a better understanding of the relationship between fire and materials than classroom training alone can provide, and they will be more prepared to enter a career field in fire protection. With each graduating class becoming involved in design or construction of new buildings, there should be noticeable improvements in the fire safety of buildings in Costa Rica.

The Bomberos, too, will benefit from the laboratory. They will be using it to better understand how fire behaves with different materials commonly found in Costa Rica. This will help the Bomberos improve their firefighting abilities, and therefore improve the fire-safety of the country. Finally, the biggest consequence that this fire-testing laboratory will have on Costa Rica is that it will help save lives. Fire kills many people all over the world, and Costa Rica can minimize fire-related deaths as a direct result of the lessons learned in this testing laboratory.

REFERENCES

AENOR. (2002). *About AENOR.* Retrieved September 27, 2010, from http://www.aenor.es/desarrollo/aenor/quees/quees.asp

Ames, S. (1993). Behavior of Materials in Fire. *Materials World, 1*(2), 88-91.

Apte, V. (2006). Flammability testing of materials used in construction, transport and mining Woodhead Publishing Limited.

Associated Press. (2005, July). 18 die in Costa Rica hospital fire. Retrieved from http://www.msnbc.msn.com/id/8551431/

ASTM International. (2010). *ASTM D7309-07a.* Retrieved September 27, 2010, from http://www.astm.org/Standards/D7309.htm

ASTM International. (2010). *ASTM E1354-10a.* Retrieved September 27, 2010, from http://www.astm.org/Standards/E1354.htm

ASTM International. (2007, November). *ASTM E119-10B Standard Test Methods for Fire Tests of Building Construction and Materials.* Retrieved November 8, 2010, from ASTM International: http://www.astm.org/Standards/E119.htm

ASTM International. (2007, May 1). *ASTM E1537 Standard Test Method for Fire Testing of Upholstered Furniture*. Retrieved October 8, 2010, from IHS: The Source for Critical Information and Insight: http://aec.ihs.com/document/abstract/YCSUABAAAAAAAAAA

ASTM International. (2010). *Standards: ASTM E2058 - 09*. Retrieved October 8, 2010, from ASTM International: Standards: http://www.astm.org/Standards/E2058.ht

ASTM International. *What is ASTM international?* Retrieved September 27, 2010, from http://www.astm.org/IMAGES03/whatisastm_englishpdf.pdf

Averill, J. D. (1998). Performance-Based Codes: Economics, Documentation, and Design. Thesis, Worcester Polytechnic Institute, Fire Protection Engineering.

Axelsson, J., Andersson, P., Lonnermark, A., Van Hees, P., & Wetterlund, I. (2001, April).*Uncertainties in measuring heat and smoke release rates in the Room/Corner Test and the SBI*(Nordtest Technical Report No. 477). Retrieved from Boras Fire Technology website: http://www.nordicinnovation.net/nordtestfiler/tec477.pdf

Barbrauskas, V., & Peacock, R. (1990, October). Heat Release Rate: The Single Most Important Variable in Fire Hazard. *Fire Safety Journal, 18*(3). Abstract retrieved from http://fire.nist.gov/bfrlpubs/fire92/art019.htm

Benedict.pdf (application/pdf object) Retrieved September 27, 2010, from http://science.widener.edu/svb/olcc_safety/papers/benedict.pdf

Beyler, C. L. (2001). Fire Safety Challenges in the 21st Century. Journal of Fire Protection Engineering , 11 (4).

Brushlinsky, N.N., Hall, J.R., Sokolov, S.V., & Wagner, P. (2008). World fire statistics. CTIF: International Association of Fire and Rescue Services, 13. Retrieved from http://www.ctif.org/IMG/pdf/CTIF_Report13_2008.pdf

Buchanan, A. D. (2006). Fifteen Years of Performance-Based Design in New Zealand. University of Cantebury.

Caledonia, O. (2005, May/June). NFPA Latin American Section Forum. Retrieved September 10, 2010, from National Fire Protection Association: http://www.nfpa.org/categoryList.asp?categoryID=235

Centers for Disease Control and Prevention. (2010). ***Fire deaths and injuries: Fact sheet***. Retrieved November 5, 2010, from http://www.cdc.gov/HomeandRecreationalSafety/Fire-Prevention/fires-factsheet.html

Coad, W. J.Codes and standards. In *Energy Engineering and Management for Building Systems* (pp. 111-112)

Comparative criminology | north america - costa rica Retrieved 9/27/2010, 2010, from http://www-rohan.sdsu.edu/faculty/rwinslow/namerica/costa_rica.html

Dembsey, Nicholas. (2010, September 20) Personal interview.

Dubay, Christian (2007). *Automatic Sprinkler Systems Handbook*. Quincy, Massachusetts: National Fire Protection Association.

El Consejo Directivo del Benemérito Cuerpo de Bomberos de Costa Rica . (2010, June 29). Technical Manual General Provisions Human Safety and Fir Protection Version 2010. Retrieved September 24, 2010, from Cuerpo de Bomberos de Costa Rica: Leyes, Reglamentos y Normas: http://www.bomberos.go.cr/Bomberos/pdf/leyesReglamentos/Manual_de_Disposiciones_Tecnicas_2010.pdf

Emergency Showers and Eyewash Stations. *Canadian Centre for Occupational Health and Safety*. . (January 13, 2010) Retrieved November 16, 2010, from http://www.ccohs.ca/oshanswers/safety_haz/emer_showers.html

Fire Extinguisher Types. *Fire-Extinguishers 101*. Retrieved November 16, 2010, from http://www.fire-extinguisher101.com/

Fire Testing Technology. (2007). Cone Calorimeter. Retrieved September 27, 2010, from Fire Testing Technology Ltd: http://www.fire-testing.com/html/instruments/cone.htm

Fire Testing Technology. (2007). Single Burning Item (SBI), EN 13823. Retrieved September 27, 2010, from Fire Testing Technology Ltd: http://www.fire-testing.com/html/instruments/sbi.htm

FM Global. (2010). *Research: The Fire Technology Laboratory*. Retrieved October 8, 2010, from FM Global : http://www.fmglobal.com/page.aspx?id=04010101

Hadjisophocleous, G. B. (2001). Development of Performance-based Codes, Performance Criteria and Fire Safety Engineering Methods. International Journal on Engineering Performance-Based Fire Codes , 2 (4), 127-142.

Harper, C. A. (2003). *Handbook of Building Materials for Fire Protection*. Blacklick, OH, USA: McGraw-Hill Professional Publishing.

Harris, Randy. (2010, September 17) Personal interview.

Hasegawa, H. (n.d.). Toxicity of Smoke. In *Characterization and toxicity of smoke* (p. 146). Retrieved from http://books.google.com/books?id=pzXk9v-gsikC&pg=PA146&dq=smoke+production+rate&hl=en&ei=eGf8TLSoCIKglAf42KGeBQ&sa=X&oi=book_result&ct=result&resnum=8&ved=0CEYQ6AEwBw#v=onepage&q=smoke%20production%20rate&f=false

Horowitz, H. H., & Metzger, G. (1963). A new analysis of thermogravimetric traces. *Analytical Chemistry, 35*(10), 1464-1468.

International Organization for Standardization. (2010). *About ISO.* Retrieved September 27, 2010, from http://www.iso.org/iso/about.htm

Ishida, K. S. (1975). *Patent No. 3898462.* United States.University of Canterbury2010*Fire Engineering: Facilities*

Isman, K., (2005) Do Quick-Response Sprinklers Provide Better Fire Protection?, *Fire Protection Engineering Magazine.* Retrieved November 23, 2010, from http://www.fpemag.com/archives/enewsletter.asp?i=1

Janssens, M. (2010). Bench-Scale Reaction-to-Fire Tests. In *Fire Retardancy of Polymeric Materials* (, pp. 358-374) Taylor and Francis Group, LLC,.

Karlsson, B. N. (2002). Using Results from Performance-Based Test Methods for Material Flammability in Fire Safety Engineering Design. Journal of Fire Protection Engineering , 12 (2).

Lawson, J. R. (2009). A history of fire testing: Past, present, future. *Journal of ASTM International, 6*(4), November 3, 2010.

List of NFPA codes & standards Retrieved 9/27/2010, 2010, from http://www.nfpa.org/aboutthecodes/list_of_codes_and_standards.asp

Lomakin, S. M., & Zaikov, G. E. (1999). General methods for testing of polymer materials flammability. In *Ecological Aspects of Polymer Flame Retardancy* (, pp. 9-22). The Netherlands:

National Fire Protection Association, “Deadliest.large–loss fires, 25 largest fire losses in U.S. history,” http://www.nfpa.org/itemDetail.asp?categoryID=954&itemID=23352&URL=Research%20&%20Reports/Fire%20statistics/Deadliest/large-loss%20fires, July 2008

National Fire Protection Association (2006). *NFPA 10: Standard for Portable Fire Extinguishers*. Quincy, Massachusetts: National Fire Protection Association.

National Fire Protection Association. (2010). MOUs. Retrieved September 24, 2010, from National Fire Protection Association: http://www.nfpa.org/itemDetail.asp?categoryID=1575&itemID=38375&URL=About%20NFPA/International/Code%20activity/MOUs&cookie%255Ftest=1&cookie%255Ftest=1

National Fire Protection Association. (2010). Overall Fire Statistics. Retrieved from http://www.nfpa.org/categoryList.asp?categoryID=413&URL=Research/Firereports/Overall fire statistics&cookie_test=1

National Microscale Chemistry Center. (2002). *About Microscale Chemistry.* Retrieved September 27, 2010, from http://microscale.org/about.asp

NAVSEA.*Cone calorimeter.* Retrieved September 27, 2010, from http://www.dt.navy.mil/sur-str-mat/fun-mat/fir-pro-sea/con-cal/index.html

Nicholas A. Dembsey's homepage. Retrieved September 27, 2010, from http://users.wpi.edu/~ndembsey/

National Institute of Standards and Technology (2010). *BFRL Project: Measurements and Standards Test Bed for Greenhouse Gas Emissions in the Large Fire Laboratory*. Retrieved Septermber 25, 2010. http://www.nist.gov/bfrl/highperformance_buildings/performance/meas-stds_greenhousegas_emis.cfm

Prospective Students, Department of Fire Protection Engineering, University of Maryland. Retrieved September 27, 2010, from http://www.enfp.umd.edu/prospective/index.html

Rangwala, A. (2010, May 5). Retrieved September 27, 2010, from WPI Fire Protection Engineering: Combustion Lab: http://combustionlab.wpi.edu/

Residential and Quick Response Sprinklers. *National Fire Sprinkler Association*. Retrieved November 23, 2010, from http://www.nfsa.org/info/fyi/resqck.html

Rockwell, Scott. (2010, October 6) Personal interview.

Schartel, B.Developing fire: Forced flaming combustion. In *Fire Retardancy of Polymeric Materials* (pp. 396). 2010: Taylor and Francis Group, LLC.

Servicios y Recursos Estudiantiles Retrieved September 27, 2010, from http://www.ucr.ac.cr/estudiantes/servicios-recursos/

Southwest Research Institute. (2010). *Large-scale Fire Resistance Testing Services.* Retrieved September 19, 2010, from http://www.swri.org/4org/d01/fire/firetech/tstconst.htm

Stollard, P., & Abrahams, J. (1999). *Fire from First Principles : A Design Guide to Building Fire Safety*. London, GBR: Spon Press.

TA Instruments (2010). *Thermogravimetric Analysis.* Retrieved October 11, 2010 from http://www.tainstruments.com/product.aspx?siteid=11&id=11&n=1

Tavares, R. M. (2008). Prescriptive Codes Vs. Performance-Based Codes: Which One Is The Best Fire Safety Code For The Brazilian Context? Safety Science Monitor , 12 (1).

The National Institute of Standards and Technology. (2010, October 5). *Large Fire Laboratory Operations Project*. Retrieved October 8, 2010, from NIST: Fire Protection: http://www.nist.gov/el/fire_protection/buildings/large_fire_lab_operations.cfm

Underwriters Laboratories Inc. (2010). *Fire Equipment Services.* Retrieved September 19, 2010, fromhttp://www.ul.com/global/eng/pages/offerings/industries/lifesafetyandsecurity/fireequipment/

Underwriters Laboratories Inc. (2010). *Large-scale Fire Research.* Retrieved September 19, 2010, from http://www.ul.com/global/eng/pages/offerings/industries/buildingmaterials/fire/technology/research/

University of Canterbury. (2010). Fire Engineering: Facilities. Retrieved September 26, 2010, from University of Canterbury: Civil and Natural Resources Engineering: http://www.civil.canterbury.ac.nz/fire/fe_facilities.shtml

University of Maryland: Department of Fire Protection Engineering. (2010). *ENFP 415 - Fire Dynamics: Fundamentals of Fire Phenomena (3 credits)*. Retrieved November 8, 2010, from Undergraduate Courses: http://www.fpe.umd.edu/undergrad/courses/enfp415.html

University of Maryland: Environmental Safety (2010). *General Laboratory Safety Practices.* Retrieved September 26, 2010 from http://www.des.umd.edu/ls/labguide/one.htm

University of Maryland. (2009). *FireTEC: Fire Testing and Evaluation Center*. Retrieved November 8, 2010, from University of Maryland: Department of Fire Protection Engineering: http://www.firetec.umd.edu/tests.php

University of Maryland. (2009). *Tests: Compartment Fires*. Retrieved November 8, 2010, from University of Maryland: Department of Fire Protection Engineering: http://www.firetec.umd.edu/tests-compartment.php

University of Maryland. (2009). *Tests: Optical Density of Smoke - ASTM E662*. Retrieved November 8, 2010, from University of Maryland: Department of Fire Protection Engineering: http://www.firetec.umd.edu/tests-optical.php

University of Maryland. (2009). *Tests: Surface Flammability - ASTM E-162*. Retrieved November 8, 2010, from University of Maryland: Department of Fire Protection Engineering: http://www.firetec.umd.edu/tests-surface.php

White, R. H., & Tran, H. C. (2004, September 14). *Burning rate of solid wood measured in a heat release calorimeter*. Retrieved December 2, 2010, from Wiley Online Library database: http://onlinelibrary.wiley.com/doi/10.1002/fam.810160406/abstract

Worcester Polytechnic Institute: Department of Fire Protection Engineering. (2010). *Differential Scanning Calorimeter*. Retrieved October 8, 2010, from WPI: Fire Protection Engineering: http://www.wpi.edu/academics/Depts/Fire/Research/dsc.html

Worcester Polytechnic Institute: Department of Fire Protection Engineering. (2010). *Thermogravimetric Analyzer*. Retrieved October 8, 2010, from WPI: Fire Protection Engineering: http://www.wpi.edu/academics/Depts/Fire/Research/tga.html

WPI department of fire protection engineering - fire science laboratory: Standard operating procedures and safety guidelines. Retrieved 9/27/2010, 2010, from http://www.wpi.edu/Academics/Depts/Fire/Lab/Safety/introduction.html

York High School. (2000, June 25). *Fume Hood*. Retrieved October 8, 2010, from Basic Laboratory Equipment: http://www.newton.dep.anl.gov/york/question9.html

Appendix A: Glossary

Term	Definition
a) Ambient Heat Transfer	The heat generated by the equipment that escapes and surrounds the outside of the equipment.
b) Calorimetry (Background)	The science of measuring amount of heat produced in chemical and physical reactions
c) Combustion (Background)	The process of burning fuel and oxygen to produce heat and light (can be identified by the production of flames)
d) Filtration Aggregate (Background)	Loose, particulate materials (such as pebbles or gravel) used to filter exhaust produced in a fire
e) Fume hood (Background)	A device over a piece of equipment or enclosed area used to collect or extract exhaust, smoke or gases so that the experiment may be conducted away from unpleasant fumes
f) Non-Combustion (Background)	The process of oxidation in which heat is produced but light is not
g) Pre-Combustion (Background)	The stage of a fire in which there is thermal or chemical decomposition of the material, giving off water vapor and gases, but no ignition and flame production
h) Qualitative (Introduction)	Refers only to the characteristics of the described subject, rather than numerical measurements or values
i) Quantitative (Introduction)	Refers only to quantity or numerical value of the described subject
j) Self-heating (Background)	The process of a material heating itself to its ignition temperature to spontaneously combust
k) Suppression system (Introduction)	A system designed to extinguish or subdue a fire
l) Thermal radiation (Background)	Energy emitted by hot surfaces
m) Triangle of Fire (Background)	Also known as the Fire Triangle. The principle that heat, oxygen, and fuel are all required simultaneously to maintain a fire

Sources:

a. None
b. http://www.science.uwaterloo.ca/~cchieh/cact/c120/calorimetry.html
c. http://www.eoearth.org/article/Combustion; http://www.answers.com/topic/combustion
d. http://dictionary.reference.com/browse/aggregate; Randy Harris
e. http://www.answers.com/topic/fume-hood
f. None
g. http://www.nwcg.gov/pms/pubs/glossary/p.htm
h. http://www.google.com/search?hl=en&safe=off&client=safari&rls=en&defl=en&q=define:qualitative&sa=X&ei=fk7tTI_yG4rZnAfEvpCOAg&ved=0CBYQkAE
i. http://www.google.com/search?hl=en&safe=off&client=safari&rls=en&defl=en&q=define:quantitative&sa=X&ei=L0_tTP-xFcqTnwfTwNSSAg&ved=0CBIQkAE
j. http://www.ilpi.com/msds/ref/flammablesolid.html
k. http://www.taftan.com/thermodynamics/RADIAT.HTM
l. http://ehs.sc.edu/modules/fire/01_triangle.htm

APPENDIX B: DETAILED EQUIPMENT INFORMATION FOR CASE STUDY

This appendix includes a detailed list of equipment used in the fire-testing laboratories that were investigated in the Case Study section of the Literature Review.

- Cone Calorimeter
  - The cone calorimeter is used specifically in this facility to acquire ignition and burning rate data. It is used to test materials such as "upholstered furniture foam and fabric combinations, various species of timber, manufactured wood products, gypsum wallboard, cables, and metro train construction materials" (University of Canterbury, 2010).
- Smoke Chamber
  - The smoke chamber is "used to measure the relative smoke propensity of materials," which "provide some insight into visibility reduction due to smoke" (University of Maryland, 2009).
- Compartment Fire Test Facility
  - The compartment fire test facility is used to observe the effects of ventilation, heat loss, fuel type, and other properties involved with fire in enclosures (University of Maryland, 2009).
- Vertical Radiant Panel
  - The vertical radiant panel allows the user to assess the flammability of a material (University of Maryland, 2009).
- Reduced Scale and Flame Spread Technique (RIFT)
  - The RIFT is used in conjunction with the cone calorimeter to measure opposed flow flame spread. It is used to test various timber products of New Zealand, including "Beech, Rimu, Radiata Pine, Macrocarpa, Plywood, Particle board, Medium Density Fibreboard and Laminated Veneer Lumber" (University of Canterbury, 2010).
- Lateral Ignition and Flame Transport Test (LIFT)
  - The LIFT apparatus is used to acquire ignition and flame spread properties.
- Wind Tunnel
  - The wind tunnel is "used to determine appropriate distributions of the Response Time Index (RTI) for a range of commercially available sprinklers" (University of Canterbury, 2010). Therefore, they test to see how long it will take for a fire to activate a sprinkler system.
- Small-scale Furnace
  - "The small-scale furnace is used for testing structural timber connections under fire conditions" (University of Canterbury, 2010).
- Atrium
  - The 1/10th scale-model atrium is used to observe the effects of spill plumes. The machine simulates a fire and investigates the path of the air into the spill plume.
- Water Mist System
  - The water mist system is used to evaluate the effects of the water mist system on compartment conditions where there is a displacement ventilation system.
- ISO Ignition Apparatus
  - The ISO ignition apparatus performs similar tests as the cone calorimeter; it is used to determine ignition and burning rate data. Typically it is used to test upholstered furniture and variations of timber.
- Furniture Calorimeter
  - The furniture calorimeter is used to measure the heat release rate of materials such as furniture, piled stock, and vegetation.

- Computer Resources
    - Both laboratories at the University of Canterbury have access to the following computer applications and fire modeling software:
        - SAFIR thermal and structural analysis program
        - Fire Dynamics Simulator
        - Compartment zone modeling software including CFAST, FPETool, and BRANZFIRE
        - Simulex evacuation model
        - Risk Monte Carlo Simulation Package
    - (University of Canterbury, 2010)
- Fire Propagation Apparatus (FPA)
    - The FPA provide quantitative data regarding the flammability characteristics of synthetic polymers. Specifically, measurements such as time to ignition, HRR, mass loss rate, and effective heat of combustion are found using this apparatus (ASTM International, 2010).
- Room Calorimeter
    - The room calorimeter is used to test the flammability properties and burning behavior of upholstered furniture, mattresses, surface products, and textile wall coverings (Worcester Polytechnic Institute: Department of Fire Protection Engineering, 2010). The burning behavior tests are documented using photographic or video recording equipment and are conducted to describe the response of materials to heat and flame under specific conditions (ASTM International, 2007).
- Differential Scanning Calorimeter (DSC)
    - The DSC measures heat flow and temperatures corresponding to thermal transitions in a material. Typical properties that are measured in these experiments include glass transitions, “cold” crystallization, phase changes, melting, crystallization, product stability, cure kinetics, and oxidative stability (Worcester Polytechnic Institute: Department of Fire Protection Engineering, 2010).
- Thermogravimetric Analyzer (TGA)
    - The TGA is used to measure the thermal stability and composition of a material in order to determine weight changes of the material as a function of temperature or time (Worcester Polytechnic Institute: Department of Fire Protection Engineering, 2010).
- Fume Hood
    - The fume hood is a very commonly used piece of equipment in all types of laboratories (chemical, fire, environmental, etc.). Its purpose is to protect researchers from fumes produced by experimentation by vacuuming the air out of the laboratory (York High School, 2000).
- Laser Doppler Anemometer (LDA)
    - The LDA is a laser system used to measure the flow velocity of flame or smoke production of a fire (Scott Rockwell, personal communication, October 6, 2010).
- Environmental Chamber
    - This piece of equipment was constructed by the FPE students at WPI. Its purpose is to provide a cooling environment using nitrogen gas or dry ice in order to observe a material’s decomposition when exposed to flame without progressing to combustion (Scott Rockwell, personal communication, October 6, 2010).
- Round Hot Plate Test Apparatus and V-Shaped Hot Plate Test Apparatus
    - These hot plates are used to heat materials and as an ignition source (Scott Rockwell, personal communication, October 6, 2010).
- Sieve Shaker
    - With recent studies in dust combustion, this piece of equipment is used at WPI for the purpose of sieving aggregate materials in order to get the desired particle size of dust (Scott Rockwell, personal communication, October 6, 2010).

- Mass Flow Controllers
    - Mass flow controllers are used to control the mass flow of gases used in experimentation (Scott Rockwell, personal communication, October 6, 2010).
- Precision Micro-Feeder
    - Information on this piece of equipment for the purpose of fire testing could not be found.
- Infrared (IR) Gas Analyzer
    - The IR gas analyzer is used to analyze the gases and smoke produced from a fire test. It can test for elements such as oxygen, carbon monoxide, carbon dioxide, and many more (Ishida, 1975).
- High Speed Camera
    - The high-speed camera is used for recording purposes in order to observe combustion or flame flow in slow motion (Scott Rockwell, personal communication, October 6, 2010).
- Precision Mass Balance
    - The precision mass balance is simply a mass balance that is very strictly calibrated and can produce precise measurements (Scott Rockwell, personal communication, October 6, 2010).

Sources:

ASTM International. (2007, May 1). *ASTM E1537 Standard Test Method for Fire Testing of Upholstered Furniture*. Retrieved October 8, 2010, from IHS: The Source for Critical Information and Insight: http://aec.ihs.com/document/abstract/YCSUABAAAAAAAAAA

ASTM International. (2010). *Standards: ASTM E2058 - 09*. Retrieved October 8, 2010, from ASTM International: Standards: http://www.astm.org/Standards/E2058.htm

Ishida, K. S. (1975, August 1975). *Patent No. 3898462.* United States.

University of Canterbury. (2010). *Fire Engineering: Facilities*. Retrieved September 26, 2010, from University of Cantebury: Civil and Natural Resources Engineering: http://www.civil.canterbury.ac.nz/fire/fe_facilities.shtml

University of Maryland. (2009). *Tests: Compartment Fires*. Retrieved November 8, 2010, from University of Maryland: Department of Fire Protection Engineering: http://www.firetec.umd.edu/tests-compartment.php

University of Maryland. (2009). *Tests: Optical Density of Smoke - ASTM E662*. Retrieved November 8, 2010, from University of Maryland: Department of Fire Protection Engineering: http://www.firetec.umd.edu/tests-optical.php

University of Maryland. (2009). *Tests: Surface Flammability - ASTM E-162*. Retrieved November 8, 2010, from University of Maryland: Department of Fire Protection Engineering: http://www.firetec.umd.edu/tests-surface.php

Worcester Polytechnic Institute: Department of Fire Protection Engineering. (2010). *Differential Scanning Calorimeter*. Retrieved October 8, 2010, from WPI: Fire Protection Engineering: http://www.wpi.edu/academics/Depts/Fire/Research/dsc.html

Worcester Polytechnic Institute: Department of Fire Protection Engineering. (2010). *Thermogravimetric Analyzer*. Retrieved October 8, 2010, from WPI: Fire Protection Engineering: http://www.wpi.edu/academics/Depts/Fire/Research/tga.html

York High School. (2000, June 25). *Fume Hood*. Retrieved October 8, 2010, from Basic Laboratory Equipment: http://www.newton.dep.anl.gov/york/question9.html

Rockwell, Scott. (2010, October 6) Personal interview

Appendix C: Interviews and Laboratory Tour Notes

C.1 - Nicolas Dembsey: interview 1 (WPI)

Date: 20 September 2010
Meeting with Dr. Nicholas Dembsey
Attendance: Michael Berlied, Nicholas Dembsey, Elena Fajardo, Andrew Mackenzie, Chelsea Tuttle

- There are two types of fire-testing laboratories:
  - University-level (like WPI's – we have bench-scale) – small, less capacity to test large things
    - Have an educational purpose
    - Usually requires minimum of 1,000-2,000 square feet
  - Industrial/commercial – Michigan State has a fire resistance laboratory that can test larger components (for example it can test structural stability under thermal conditions)
    - These types of laboratories have residential or larger-scale capabilities
    - These laboratories deal with certification of materials (for example, Underwriter's Labs and Tyco)
    - Cost is an issue – it can cost millions of dollars to run one test. You need to consider where this money is coming from
      - Many governmental laboratories become privatized
    - Size is also an issue – structural tests can require up to 10,000 square feet for set-up
- It is difficult to have both educational and certification purposes for a single laboratory
  - There are many codes and calibrations necessary for a certification laboratory, and an educational laboratory would require the constant changing of calibrations
- For designing a fire-testing laboratory:
  - You need to know your goals – what do you want to do with this lab?
  - There are a variety of ways to set up a laboratory – you can even modify a chemistry laboratory to fit the needs of a fire dynamics laboratory
  - Bench-scale is a good start
- Prescriptive Vs. Performance:
  - UK, New Zealand, Australia are all advancing towards performance-based
    - N.Z. is farthest along and is a good example
  - Performance-based focuses on Engineering Science measurements and applications
    - This type is more difficult to use for certifications because it might not meet all of the required codes and standards
  - Prescriptive-based does not always produce quantitative data and therefore is less useful in simulations
    - Fire science is only about 50 years old in the U.S.
      - There is not a lot of information about it and we tend to rely on prescriptive-based testing in the United States (some elements are peformance-based)
- Sizes of laboratories:
  - Microscale Level
    - Thermal decomposition of materials
      - Example: calorimetry
  - Bench-scale Level
    - Reaction to Fire
      - Flammability
      - How materials burn

            - Example: Cone Calorimeter
        - Fire Resistance
            - How assembly behaves in thermo-chemical surroundings
    - Large-scale
        - Large-scale testing done in industrial or commercial settings
- Recommendations:
    - Start with micro and bench-scale
        - Cone Calorimeter
    - Should have a staff member running the laboratory
        - Responsibility, continuity, education, maintenance
            - Maintenance and staffing require s budget
    - Look into Fire Testing Technologies for equipment

C.2 - Nicolas Dembsey: Email Interview

Date: 29 November 2010

-*Below is an email questionnaire we sent to Professor Nicolas Dembsey (WPI) about some concerns that we had as well as a second opinion to different subjects related to the scope of our project. The red is his responses; the black is the email we sent to him*

Dear Professor Dembsey,

My name is Elena Fajardo and I am a member of the Bomberos IQP team currently working in Costa Rica. Our IQP group met with you last term regarding FPE courses and laboratory equipment, which was very helpful for our project.

For a recap, the goal of our IQP project is to recommend 3-4 pieces of laboratory equipment, as well as laboratory safety for the University of Costa Rica's (UCR) fire-testing laboratory. UCR would like to use their laboratory equipment to support their FPE courses. They also provided us a list of equipment they wanted us to analyze, and after extensive research, we were able to determine the top 5 pieces of equipment (in order of importance), which are as follows:

1) Cone calorimeter (from Govmark)
2) Single Burning Item (from
3) Radiant Panel Flame Spread Tester (from Govmark)
4) Smoke Density Tester (from Govmark)
5) Flammability Testers, horizontal and vertical samples (from Fire Testing Technology Ltd))

We just have a few more questions regarding equipment and safety of equipment and included our assumptions based on our current research. If you can provide us your professional opinion, we would greatly appreciate it. Also, regarding safety, we emailed our questions to Randy Harris as well, so if you cannot respond to these questions that is fine.

1. Regarding our list of equipment, do you agree with our findings? Or do you think other pieces of equipment would be more applicable?

NAD: The above noted 5 items are fine for bench scale testing and experiments.

2. What is the best type/setup of fire sprinklers for a fire-testing laboratory? What type of sprinkler does the main WPI fire lab have?

a. Quick Response/Fast Response/Standard
b. Pendent/Flush/Recessed Pendent/Sidewall/Upright

Our belief: We believe quick response is the best. Based on chemical laboratory tests, quick reaction sprinklers work just as well or better than standard sprinklers. They are quick reacting and designed to increase survivability within the room whereas fast response sprinklers are meant to save lives outside of the room of ignition. In a fire lab there is a higher chance of ignition within the room. Therefore quick response sprinklers are most suitable.

NAD: The sprinklers in a bench scale apparatus type fire lab should be specified consistent with the general contents of the lab including gas bottles and storage of combustible materials, etc. I would not look at the sprinklers as a "first line of defense". The "first line of defense" is following appropriate lab safety procedures. The sprinklers should be viewed as a "backup" to control testing fires if they get out of control (which should not happen if safety procedures are followed) and/or to handle non-testing fires involving the contents of the lab. Note that instrumentation may or may not handle being wet from a sprinkler spray. As such, the focus should be on prevention as the lab is a controlled environment.

2. Which fire extinguishers are necessary for a fire lab?
a. Is a type B and D fire extinguisher necessary?

Our belief: Types A and C for conventional and electrical fires are necessary for a fire lab. However, type B is not necessary because gasoline/oil will not be in use in the laboratory. Also, Type D is not necessary because chemicals such as Magnesium will not be in use either. If these beliefs are incorrect, please let us know.
NAD: Do NOT assume that a given fuel type will not enter the lab. It would be better to assume all fuel types could be in the lab for testing.

3. Is an emergency shower/eye wash station necessary?

Our belief: According to ANSI Z358.1, it is necessary to have one in a fire lab in case exposed to potent chemicals, including vapors.
NAD: A shower/eye wash station is a good idea.

4. What type of gas detector(s) is necessary according to NFPA standard? What type/model does the WPI laboratory have?
a. CO?
NAD: Ideally you have detectors for each of bottled gases that are used to support the operation of the various bench scale apparatuses.

5. According to NFPA, what risk classification is a fire laboratory and why?
a. Low/medium/high

Thank you very much for your time, and we look forward to hearing from you.

Sincerely,
Elena Fajardo

C.3 - RANDALL HARRIS: WPI FIRE-LABORATORY TOUR

17 September 2010
Attendance: Michael Berlied, Elena Fajardo, Randall Harris, Andrew Mackenzie, Chelsea Tuttle

We met with Randall Harris, the laboratory technician of WPI's fire research laboratory. We talked with him about different types of testing equipment and safety measures. The following are our notes from this tour.

- You can find abstracts for descriptions of ASTM and UL standards on their websites (to view the full standards requires purchasing)
- Basic measuring tools:
    - Micrometer
    - Thermocouple reader (Omega Company)
    - Heat flux gauge
        - Reads radioactive and convective heat
- Equipment:
    - Cone Calorimeter
        - Tests smoke production rate, heat release rate and can analyze oxygen depletion
        - Essential for any fire-testing laboratory
        - Can be used as a certification tool
            - Requires accessories like filtration and consumables
    - Fire Propagation Apparatus (FPA)
        - Tests vertical flame spread, heat release rate
        - ASTM E3058
        - Heat source = infrared lamps
        - More specialized than the Cone Calorimeter
    - Differential Scanning Calorimeter (DSC)
        - Tests thermal conductivity of a product (time and temperature)
            - Relies on density
- Laboratory procedures and recommendations
    - Keep calibrations and ventilation in mind
    - A research laboratory entails the testing of material properties
    - Use marble basings for bench-scale equipment
        - It is heavy enough that vibrations from machinery will not disturb the experiment
    - WPI's lab is 2,000 square feet
    - You can purchase fume hoods that double as smoke analysis
    - Need access to compressed air and water
- Safety:
    - Showers
    - Blankets
    - Emergency Shut-off
    - Glasses, gloves, lab coats
    - Face shield/helmets
    - Extinguishers
    - Gas monitors
    - Alarms
    - Ventilation – fume hood, Hepa filter or HVAC
- Waste:

- WPI's laboratory does not produce much waste
- Need to consider surrounding environment
- Non-biohazard material can go in the normal trash

C.4 - Scott Rockwell: WPI Combustion Laboratory Tour

5 October 2010

Attendance: Michael Berlied, Elena Fajardo, Andrew Mackenzie, Scott Rockwell, Chelsea Tuttle

- Took notes on the equipment, set-up, and safety features of the laboratory. Below are our observations:
  - It is a good idea to have a meeting room with a projector and white board
  - Storage areas for testing and cleaning materials
  - Stainless steel piping
  - Deck system to control:
    - Different channels, voltage range, sampling rate, current
  - Gas bottles and containers – standards exist regarding the storage of these
    - Air, Nitrogen, Oxygen, Carbon Dioxide, Carbon Monoxide
  - Computers in a centralized area
    - No laptops because they are easily stolen
  - Cameras to record images and videos
  - Laser Doppler to measure flow, speed, and temperature
    - Does not interrupt flow
  - Infrared thermometers (enable you to observe the temperature before touching it)
  - Igniters – handheld torches are good
  - "Environmental Chamber" – built in the laboratory by researchers, filled with Carbon Dioxide (dry ice effect)
  - Dust room – built with 4-hour doors and walls
  - Construction area for building experiments and samples:
    - Drill press
    - Mounted vice
    - Cabinets (for screws, bolts, nails, etc.)
  - Safety:
    - Oxygen and gas analyzers
    - Carbon Monoxide detector – one that matches your needs (you don't want false alarms)
    - Gas access close to experiments to avoid running cables
      - Use tank air
    - Standard fume hood
    - Labels/tags for gas lines to mark "in use" to avoid accidents
    - Respirators for conductors of experiments
      - For dust and organic vapors
    - Fire cabinet to store flammables, sharp objects and hazardous waste
    - Make sure all materials are labeled
    - Rubber container to carry glass bottles (avoid dropping)
    - Universal absorbent (in event of a chemical spill)
    - First Aid station
    - Eye wash station
    - Chemical wash station
    - Fire blankets
    - Fire extinguishers
    - Carbon Dioxide extinguishers
    - Dry chemical extinguisher
    - Glasses, gloves, welding gloves, lab coats
    - Sprinklers
    - "Don't work alone" buddy system
    - Water access with flow indicators
    - Metal trash cans

C.5 – JACINTO SABORÍO: EMAIL INTERVIEW REGARDING BOMBEROS LABORATORY PLANS

****Below is an email interview we sent to our sponsor Jacinto Saborío (Engineer of Cuerpo de Bomberos) regarding what their plans for use of the laboratory would be. Our email is in black, his responses are seen in Red****

Hola Jacinto,

Tenemos algunas preguntas para usted o Don Esteban que son:

1. ¿Cuáles son sus metas para el laboratorio de protección contra incendios? Por favor nos dice los especificos. Es necesario que nosotros sabemos las metas de los Bomberos para escribir nuestro informe.

Verificar las características del producto en el proceso de Investigación de Incendios.
Revisión de los productos que ingresan al país y su aceptación por parte del Cuerpo de Bomberos.
Corroborar las especificaciones de los productos que indican los profesionales de la construcción.

2. ¿Cómo van usar los Bomberos el laboratorio?

Mediante un convenio que se analizaría a futuro con la Universidad de Costa Rica y con el pago de servicios.

3. ¿Cuándo planean a usar el laboratorio?

Desde el mismo momento que el laboratorio esté disponible.

Queríamos clarificar el relación entre los Bomberos y UCR con este proyecto. Entonces si puede hacerlo, sería muy bueno para nosotros.

Muchas Gracias

-Elena

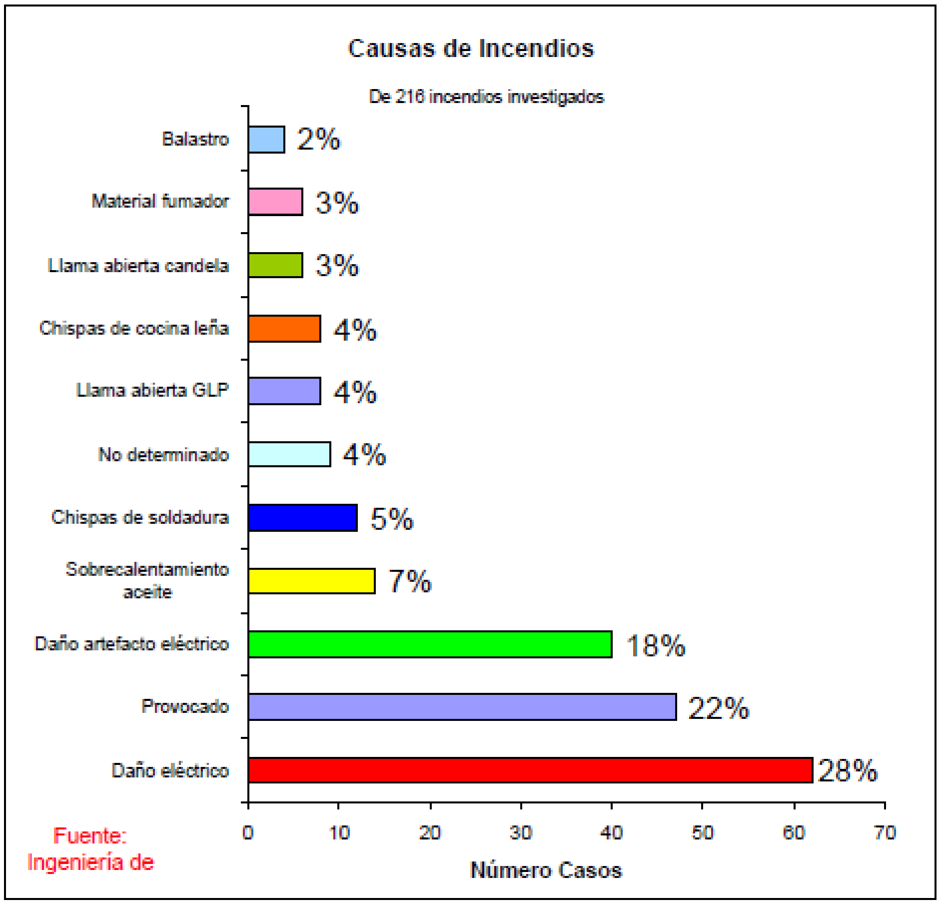
APPENDIX D: MATERIALS RESEARCH ITEMS

D.1 - BOMBEROS FIRE STATISTICS DATA

ALL of the following graphs were retrieved from the computer of Jacinto Saborío of the Engineering Department of the Cuerpo de Bomberos

This figure shows the causes of investigated fires throughout Costa Rica in 2008

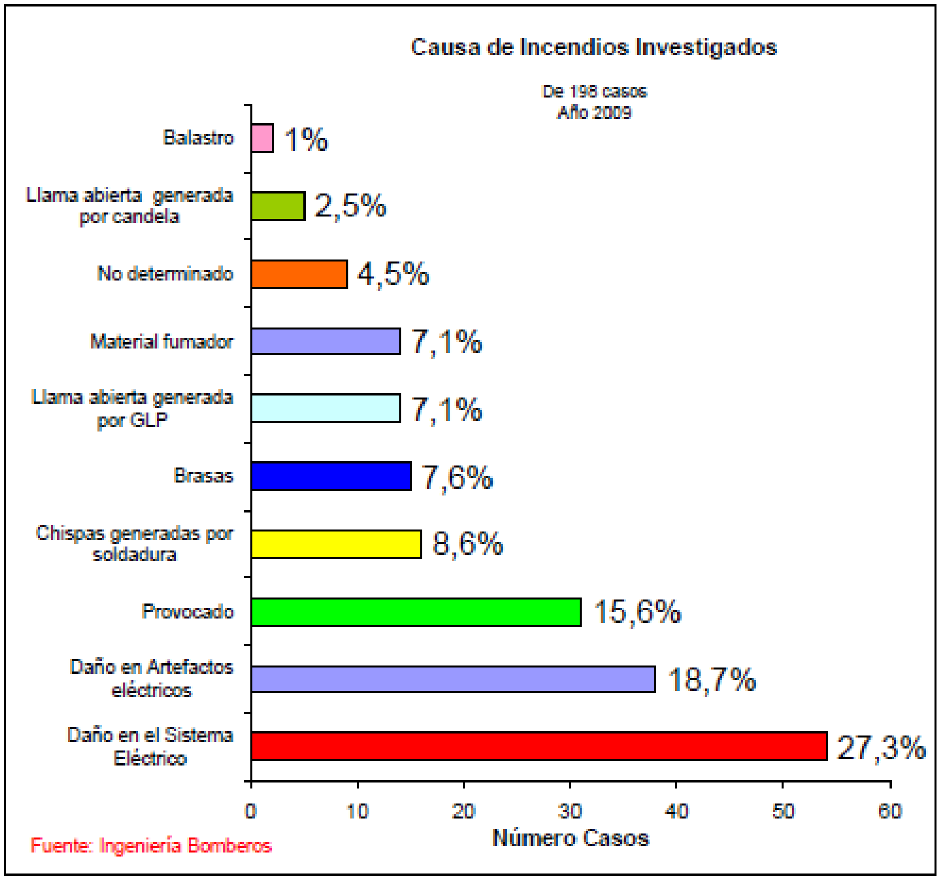
Por Causa	Porcentaje	
Daño eléctrico	62	28%
Provocado	47	22%
Daño artefacto eléctrico	40	18%
Sobrecalentamiento aceite	14	7%
Chispas de soldadura	12	5%
No determinado	9	4%
Llama abierta GLP	8	4%
Chispas de cocina leña	8	4%
Llama abierta candela	6	3%
Material fumador	6	3%
Balastro	4	2%
	216	100%



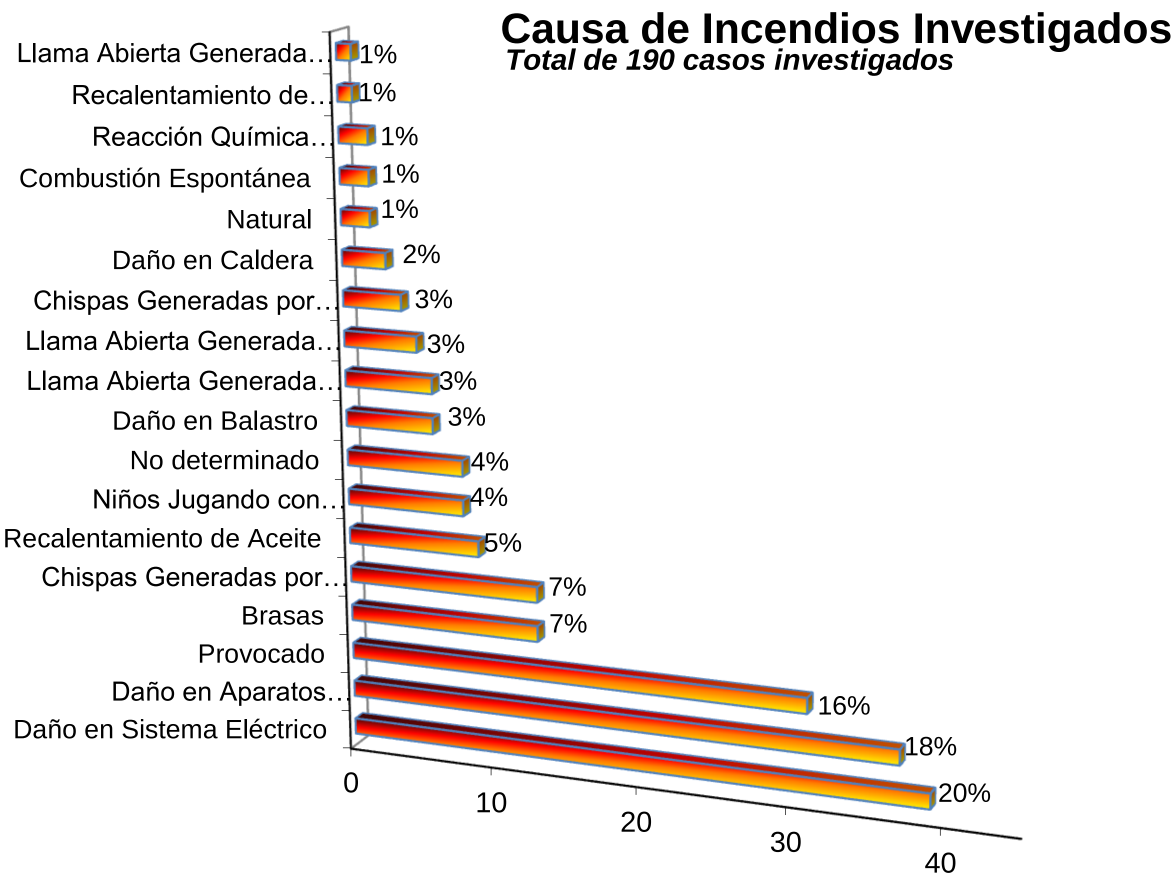
This figure shows the causes of investigated fires throughout Costa Rica in 2009

Causa de Incendios

	Casos	%
Daño en el Sistema Eléctrico	54	27,3
Daño en Artefactos eléctricos	38	18,7
Provocado	31	15,6
Chispas generadas por soldadura	16	8,6
Brasas	15	7,6
Llama abierta generada por GLP	14	7,1
Material fumador	14	7,1
No determinado	9	4,5
Llama abierta generada por candela	5	2,5
Balastro	2	1
Total	198	100



Daño Sistema Eléctrico: es el daño en los elementos que proveen electricidad a una estructura como cables, tomacorrientes, apagadores, cajas de disyuntores. Este se debe al no cumplimiento del Código Eléctrico Nacional, a la falta de mantenimiento, a la utilización de componentes no certificados y a prácticas inadecuadas como por ejemplo el uso de varias extensiones eléctricas unidas



This graph shows the causes of the investigated fires of 2010 from January to September

D.2 - BUILIDING VISIT NOTES

Heredia Hospital, San Vicente de Paul
Date: 4 November 2010
Members Present: Michael Berlied, Elena Fajardo, Andy Mackenzie, Chelsea Tuttle
Sponsors Present: Patricio Becerra, Marcela Shedden, Jacinto Saborío
Hospital Engineer Present: Aldo Protti

1. Tour was given by Engr. Aldo Protti
2. Caja Costariccense de Seguro Social – means it is a public hospital
3. Built with NFPA standards
4. Fire precaution systems/equipment include:
    a. Sprinkler system (about every ten feet, also with between 6 feet)
    b. Detectors
    c. Manual Extinguishers (Water and CO_2)
5. Construction materials used:
    a. Concrete (exterior walls)
    b. Gypsum X (interior walls): has a fire resistance of 30-60 minutes. Has more humidity than regular gypsum
    c. Durock (concrete board, used for ceiling?)
    d. Plastic
6. Windows (Aluminum? With silicon caulking)
7. Rubber foot runners on walls bottom
8. Plastic “corner guards”
9. Suspended ceiling (probably for electrical system access)
    a. Tiles are the same as US (fire resistant)
10. Hospital has been open for 3 months and is a public hospital
11. 6 buildings interconnected
12. NFPA other codes
13. Newest hospital in Costa Rica
14. Central Command Center (monitors everything in the hospital)
    a. Video cameras
    b. Rec phones
    c. Alarms
    d. Gas to extinguish fire
15. Fire doors have 2-3 hour fire resistance
16. More than 3000 sprinkler systems
17. Elevator area is the safest area in the whole hospital
    a. There are local fire emergency phones
    b. Automatic doors in case of emergency
    c. Control system controls the doors
18. Doors at staircases are fire resistant, close automatically so that air doesn’t travel between rooms during a fire
19. Hallways follow standard width
20. Hallways that connect one building to another are important
    a. Automatic doors to close off fires
    b. Lights working 24/7
    c. Fire hose

    d. Emergency Exit
21. Hallway to office rooms have double doors
22. Sick people can go through hallway to see doctors without getting into contact with other people
23. There are special curtains separating beds
24. Machine Room
25. Hospital has 3 tanks of water
    a. Each one has 365,000 liters of water
    b. 2 are for portable water, 1 is reserved for extinguishing fires
26. If a fire is really big, all 3 tanks will be connected
27. All systems are automatic, which is important
28. All hospitals have a fire system
29. This hospital has 5 floors, each floor has a different color
30. 3 NFPA building standards have been published: 2005, 2007, 2010
    a. All future buildings in Costa Rica must follow the standards

San Juan de Dios Hospital
Date: 11 November 2010
Members Present: Michael Berlied, Elena Fajardo, Andy Mackenzie, Chelsea Tuttle
Sponsors Present: Patricio Becerra, Marcela Shedden, Jacinto Saborío
Hospital Engineer Present: Don Jose Francisco

1. First Hospital in Costa Rica
    a. Established in 1845
    b. 5 km of hallways
        i. Mostly horizontal
        ii. No high-rise buildings
2. Talked to chief engineer of the hospital, Don Jose Francisco
3. Hospital management is changing
    a. Three years ago there was a corruption scandal
4. Construction/Common Materials
    a. Gypsum
    b. Durock
    c. Concrete
    d. Wood
        i. Trying to eliminate wood with new construction
    e. Paints
    f. PVC
5. Buildings are hard to update with construction because many have historical significance
    a. Using metal and gypsum to replace wood with new construction
6. Safety
    a. No sprinkler systems or suppression systems
    b. Fire extinguishers were missing/outdated
    c. Electrical wires hanging from ceiling/trees
    d. Exposed circuit boxes/inadequate wire housing
    e. Security bars covering windows
7. Boiler Room

a. Gas oil
b. Accident occurred where oil leaked into a river
    i. Blocked off trench as a result

8. Material Warehouse
    a. Historical Building
    b. Paints which can produce toxic gases
    c. Large quantities of wood
    d. Glass
9. Laundry Room
    a. Industrial sized machinery
    b. Exposed steam piping
    c. Fire hoses/extinguishers existed
    d. Large amounts of lint/excess linens
    e. Dust accumulated in suspended ceiling
    f. Exposed wiring for fans
10. File storage
    a. Large room packed from floor to ceiling with hundreds of thousands of patients files
    b. Incandescent/Fluorescent lighting tubes leave burn marks in ceilings
        i. Lights can reach 600 degrees Celsius
    c. Burn marks on outlets from electrical failures
11. Small warehouse
    a. Historical Building
    b. Made of wood
    c. Medical supplies in cardboard boxes
    d. Barrels of alcohol stacked next to each other

Hospital Mexico
Date: 18 November 2010
Members Present: Michael Berlied, Elena Fajardo, Andy Mackenzie, Chelsea Tuttle
Sponsors Present: Patricio Becerra, Marcela Shedden, Jacinto Saborío

1. Established 1969
2. Materials Identified
    a. leather
    b. concrete
    c. tile floor
    d. rubber wall runners
    e. suspended ceiling
    f. fluorescent lighting systems
    g. fiberglass
    h. curtains (mixture of materials; polyester, cotton, other)
    i. bedding materials
        i. blankets(polyester)
        ii. sheets (cotton/polyester mix)
        iii. mattresses

iv. patient gowns
j. cubical materials (felt squares as walls)
k. steel roof
l. plastic wall handles
m. wood shop materials (all wood, wood dust)
n. acoustic suspended ceiling tiles
i. PB 193307 Fissured square lay in humiguard plus; 25 Flame Spread 50 Smoke Developed
o. particle wallboards (drywall, concrete boards)

3. Initial Fire- Safety Impressions
   a. fire extinguishers always visible
   b. alarm system with bells
   c. fire systems (hose boxes, fire axes)
      i. unimportant places and sometimes seen as inaccessible
   d. multiple computers are connected to same plug (6+)
4. Fire Pump System
   a. fire system is one year old
   b. 6 tanks under ground
      i. 2 million gallons
   c. pump system
      i. 1,000 gallon/min
      ii. 2600 PSI
5. Machine Room
   a. Backup generators
   b. liquid petroleum
   c. fresh water pumps
6. Radiology
   a. special supression (dedicated) systems
7. Evacuation Procedures
   a. Hospital divided into sectors
   b. evacuation hallways were disrupted with extra beds
   c. ICU on top (7th) big problem transporting these patients and their necessary equipment (life-support)
8. Fire Official at the hosptital runs required training program for all employees where they learn to use hoses and extinguishers for cases of emergency
   a. they use real fire-fighter garments
   b. masks and oxygen are also used for teaching
   c. 4 hours course
9. Have their own building center for repairs and storage materials seen in these building are found on number 2 above

D.3 - Construction Material Observations per Hospital

Hospital	Heredia	San Juan De Dios	Mexico
Date Visited	11/4/10	11/11/10	11/18/10
CONSTRUCTION MATERIALS			
Concrete	x	x	x
Gypsum	x	x	x
Drywall/ Fibro cemento/Fibrolit	x	x	x
Durock	x	-	x
Brick	-	x	-
Glass	x	x	x
Metal	x	x	x
Aluminum	x	-	x
Wood	-	x	x
Cinder Block	x	-	x
Structural Steel	x	-	x
Fiberglass	N/A	N/A	x
Tin (galvanized)	x	x	x
SUPPLEMENTARY MATERIALS			
Rubber	x	N/A	x
Particle Board	x	x	x
Ceramic Tiles	x	x	x
Plastic	x	x	x
PVC	x	x	x
Suspended Ceiling	x	x	x
Leather	-	-	x
Curtains	x	x	x
Bedding Materials (e.g. polyester, cotton, foam)	x	x	x
Felt Cubicle Walls	-	-	x
Clothing Materials (hospital gowns)	x	x	x

D.4 - SPONSOR MATERIALS PICKS FOR IMPORTANCE

Materials the Bomberos and UCR Determined to be the Most Important to be Tested

Bomberos	UCR
Bedding Materials	Bedding Materials
Clothing Materials	Clothing Materials
Curtain	Curtain
Drywall/Fibrolit	Drywall/Fibrolit
Felt Cubicle Walls	Felt Cubicle Walls
Gypsum	Gypsum
Plastic	Plastic
PVC	PVC
Suspended Ceiling	Suspended Ceiling
Wood	Wood
Concrete	Durock
Glass	Electrical Systems
Metal	Fiberglass
Structural Steel	Particle Board
Tin (galvanized)	Rubber

This table shows the materials which materials of our sponsors thought were the most important to them to test in the laboratory. These materials were determined from the building visits (see Appendix D.2). The highlighted yellow are the materials which both sponsors chose as important.

APPENDIX E: EQUIPMENT RESEARCH ITEMS

E.1 - UCR COURSE DESCRIPTIONS USED FOR DETERMINING CLASSES THAT WOULD USE THE EQUIPMENT

Courses are Highlighted with yellow, the descriptions of each course follow after the title

#1 PROGRAMA DEL CURSO
Licenciatura en Ingeniería Mecánica con énfasis en Protección Contra Incendios

1. Nombre del Curso: introducción a la Ingeniería de Protección Contra Incendios
2. Sigla : IM-0???
3. Requisitos : xx nivel de la carrera
4 Horas de teoría : 3 por semana

1. **JUSTIFICACIÓN**

La asignatura es la primera del plan de estudios de direcia aplicación de la Ingeniería en Protección Contra Incendios. Permite al estudiante reafirmar o modificar su elección de su carrera al mismo tiempo que la presenta el proceso y tecnológico del quehacer de la Ingenieria y la Protección contra Incendios.

2. OBJETIVOS

2.1 Generales

1. Ubicar al estudiante en el quehacer de la Ingenieía y la Protección Contra incendios en el contexto nacional, considerando el histórico y las condiciones actuales, asi corno las futuras perspectivas.
2. Brindar condiciones favorables para orientar la selección vocacional del estudiante.

2.2 Específicos

Al finalizar el curso, el estudiante será capaz de:
1. Definir los conceptos de ciencia, tecnología e ingeniería.
2. Identificar los hitos históricos más signifícativos en el desarrollo de la Ingeniería y la Protección contra incendios en el caso de Costa Rica.
3. Describir el proceso de elaboración de proyectos en ingeniería.
4. Conocer las estrategias empresariales como medio de competencia, asi como la problemática de la transferencia de tecnología.
5. Valorar los aspectos de los recursos y el medio ambiente dentro del contexto del proyecto de ingeniería.
6. Conocer de las responsabilidades y la función social del profesional en ingeniería en protección contra incendios.
7. Justificar y razonar su elección vocacional.

3. CONTENIDOS DEL CURSO
Entre los temas a estudiar están:

3.1 La seguridad, la protección contra incendios y la ingeniería en protección contra incendios: definiciones, desarrollo histórico
3.2 Análisis de los aspectos sociales, económicos, ambientales, legales y técnicos del problema de los incendios y la seguridad. La seguridad y protección contra incendios en medios urbanos, rurales y forestales. La educación en protección contra incendios.
3.3 El daño ocasionado por los incendios: causas, estadísticas nacionales e internacionales.

3.4 Instituciones nacionales e internacionales relacionadas con la seguridad y protección contra incendios. Normas y códigos de seguridad y protección contra incendios.
3.5 La seguridad en edificios, procesos, medios de transporte, etc. Comportamiento humano en situaciones de emergencia.
3.6 Situación actual en CR: regulaciones, materiales de construcción certificados procesos constructivos, el planeamiento de la edificación, del abastecimiento público de agua. Objetivos futuros a perseguir.

METODOLOGIA

El curso tendrá dos componentes pedagógicas:
a) Seminario:
En sesiones de dos horas semanaies, el estudiante discutirá, bajo la supervisión del profesor las referencias bibliográficas, elaborará ñchas, informes y proyectos sobre los lemas dei curso asignados.
b) Conferencias y mesas redondas.
Buscan enriquecer el seminario, presentando la experiencia directa de distintas personalidades invitadas.
Por las caracteristicas de ambas modalidades, la ASISTENCIA DEBE SER OBLIGATORIA.

5. BIBLIOGOGRAFÍA
- NFPA Manual de Protección Contra Incendios.Capítulos seleccionados
-Quintere: introducción a la Protección contra Incendios.

6. EVALUACION
La evaluación del curso será considerando los siguientes aspectos:
Participación..15%
Presentación de tareas e informes...................................… 15%
Exámenes cortos 30%
Proyecto...40%

#2 PROGRAMA DEL CURSO
Licenciatura en Ingeniería Mecánica con énfasis en Protección Contra Incendios

1. **Nombre del Curso**: **SEGURIDAD HUMANA**
2. **Sigla** : IM-0???
3. **Requisitos** : Sistemas de Protección Contra Incendios I, II, y Ill
4. **Horas de teoría** : 3 por semana

1. JUSTIFICACIÓN DEL CURSO
Este curso utiliza un enfoque práctico que le enseña a los estudiantes a aplicar los conceptos del Código de Seguxidad Humana en las diversas ocupaciones abarcadas por esta norma, con práctica específica en Hoteles, Edificios de y Edificios de Reunión Pública.

2. OBJETIVOS

2.1 OBJETIVO GENERAL:
Aplicar una serie de normativas referentes a la Seguridad Humana en lo referente a protección contra incendios.

2.2 OBJETIVOS ESPECIFICOS:
1. Poder diseñar salidas de emergencia con base en criterios de ingeniería.
2. Capacitar al estudiante en el equipamiento de SPCI para la seguridad humana en un edificio u ocupación.

3. CONTENIDO DEL CURSO:

3.1. Introducción

3.2. Requisitos generales

3.3. Principios de los medios de egreso

3.4. Componentes de los medios de egreso

3.5. Capacidad de los medios de egreso

3.6. Iluminación y señalización de los medios de egreso.

3.7. Caracaterísticas de la protección contra incendios.

3.8. Servicios del edificio y equipamiento de protección contra incendio.

3.9. Acabados interiores, contenidos y mobiliario.

3.10. Ocupaciones para Negocios I.

3.11. Ocupaciones para Negocios II.

3.12. Ocupaciones para Reuniones Públicas.

4. ACTIVIDADES DEL CURSO

El curso de desrrollará mediante clases magistrales, visitas a instalciones, investigación, proyecto.

5. BIBLIOGRAFÍA

NFPA: Manual de Protección contra incendios.
Normas NFPA 101 y otras,
NFPA JOURNAL: artículos.

6. EVALUACIÓN

Examen Parcial...............................20%
Participación..................................10%
Informes de Investigación...............15%
Examen Final.................................25%
Proyecto...30%

#3 PROGRAMA DEL CURSO

Licenciatura en Ingeniería Mecánica con énfasis en Contra Incendios

1. Nombre del Curso: ANALISIS DEL RIESGO
2. Sigla : IM-0??
3. Requisitos : Química 2 en SPCI (IM-0???)
4. Horas de teoría : 3 por semana

1. JUSTIFICACIÓN DEL CURSO

El curso es la base para los cursos siguientes de la especialidad de Ingeniería en Protección Contra lncendios, ya que le dará al estudiante las herramientas para poder visualizarlos riesgos de incendio, presentes en una instalación o proceso.

2. OBJETIVOS:

a. GENERAL

Capacitar a los estudiantes con los criterios para evaluación de peligros en áreas comunes y áreas peligrosas, procesos etc. Le brinda las Normativas como herramienta de control e información.

b. OBJETIVOS ESPECÍFICOS:

1. Capacitar al profesional en la evaluación del peligro, en el análisis de consecuencias y en las técnicas de análisis del riesgo aplicables al procesamiento, transporte y almacenamiento de materiales peligrosos.
2. Familiarizarse con las regulaciones, incidentes catastróficos recientes y las prácticas actual es en la seguridad de los procesos químicos.
3. Obtener experiencia en la aplicación cualitativa y cuantitativa de las herramientas de análisis del riesgo y análisis de consecuencias en aplicaciones para la seguridad de procesos y estudio de casos.

3. CONTENIDO DEL CURSO:

1. Panorámica del análisis del riesgo en procesos: Técnicas básicas de la administración de seguridad en los procesos.
2. Métodos para la identificación del peligro: Ejemplos de análisis y estudios de riesgo y operabilidad (HAZOP - Hazards and Operabity Study), de regulaciones OSHA y EPA PSM (Environmental Protection Agency Process Safety Management).
3. Análisis cualitativo del árbol de falla: Árboles lógicos, modos de falla, análisis de efecto y de consecuencia (FMEA- Failure Modes and Effects Analysis).
4. Árboles de Evento: Análisis de la confiabilidad humana. Código de computadoras para el árbol de falla/evento. Datos sobre tasa de incidentes y fallas.
5. Análisis de consecuencias: Modelos para cuantiñcar la razón de descarga y la razón de evaporación. Plumas neutras y bogantes positivos. Modelos para la dispersión de gases pesados. Códigos ALOHA para computadora.
6. Análisis de consecuencias: Gases/vapores tóxicos; incendios, BLEVES (Boiling Liquid Expanding vapour Explosion), explosiones de nubes de vapores.
7. Comparaciones de riesgos: Estudio de casos utilizando dichas técnicas y requisitos de regulaciones considerando escenarios de salud ambiental, higiene ocupacional, materiales riesgosos, riesgo de fuego o explosión.

4. ACTIVIDADES DEL CURSO
El curso se desarrollará mediante clases magistrales, asignaciones de investigación.

5. BIBLIOGRAFÍA
NFPA: Manual de Protección contra incendios.
NFPA JOURNAL: artículos.

6. EVALUACIÓN
Examen Parcial.............................20%
Informes de Investigación.............40%
Tareas..10%
Examen Final................................20%
Participación.................................10%

PROGRAMA DEL CURSO
Licenciatura en Ingeniería Mecánica con énfasis en Protección Contra Incendios

1. Nombre del Curso: SISTEMAS DE PROTECCIÓN CONTRA INCENDIOS 1
2. Sigla : IM-O???
3. Requisitos : Introducción ala Ingenieria de Protección Contra Incendios Mecánica de Fluidos, Análisis del Riesgo en SPCI.
4. Horas de teoría : 3 por semana

1. JUSTIFICACIÓN DEL CURSO

El curso presenta la mayoría de los sistemas a base de agua que se utilizan en el combate de incendios que debe conocer el profesional en ingeniería de protección contra incendios. (Los sistemas a base de rociadores, espuma y neblinas se ven en otro curso)

2. OBJETIVOS:

a. GENERAL
Presentar los sistemas de supresión de incendios a base de agua de mayor uso en Costa Rica.

b. OBJETIVOS ESPECÍFICOS:

Entender las razones del uso de agua como agente supresor.

- Conocer los componentes de los sistemas, los materiales utlizados y los procedimientos para su selección, prueba operación y mantenimiento

3. CONTENIDO DEL CURSO:

a- **El agua como agente supresor.**
Uso con base en características fisicas y químicas y aspectos económicos. Almacenaje y distrubución.

b- **Aspectos hidráulicos**
Repaso sobre conceptos básico de flujo en tuberías. Pérdidas de presión. Envejecimiento de tuberias. Ecuación de Williams y Hazen..Golpe de ariete

c- **Tuberías y accesorios utilizados.**
Descripción de componentes, requisitos que deben cumplir, métodos de instalción y prueba.
Tuberías, válvulas, soportes y accesorios: materiales, procesos de fabricación normas Accesorios especiales: gabinetes, mangueras, hidrantes, etc.
Redes públicas y privadas.

d- **Sistema de tuberías fijas para gabinetes y mangueras**
Descripción de clases de sistemas y sus componentes.
Relación con el edificio: accesos para operación, soportería, aspectos sísmicos, penetraciones en barreras contra fuego o humo.
Cálculos hidráulicos.
Requerimientos especiales para edificios altos.

e- **Bombas de agua para protección contra incendios.**
Tipos de bombas principales y auxiliares utilizadas, requerimientos de operación, Motores impulsores y sistemas de control; confiabilidad.
Requisitos de instalación y prueba.

f- **Pruebas de caudal y presión en redes.**
Procedimientos de medida y cálculo para determinar la capacidad de redes.

4. **ACTIVIDADES DEL CURSO**

El curso se desarrollará mediante clases magistrales, asignaciones de investigación, visitas a instalaciones, uso de programas de cálculo.

5. **BIBLIOGRAFIA**
NFPA : Manual de Protección contra incendios
Normas NFPA 14, 2022,24.
NFPA JOURNAL: artículos.

6. **EVALUACIÓN**
Examenes Parciales....................55%
Informes de Investigación............15%
Examen Final..............................25%
Participación...............................5%

PROGRAMA DEL CURSO
Licenciatura en Ingeniería Mecánica con énfasis en Protección Contra Incendios

1. Nombre del Curso: ALARMAS Y SEÑALES
2. Sigla **:** IM-0???
3. Requisitos **:** Principios electromecánioos IM-0401, electrónica Básica para Ingenieros Mecánicos (IM-0412).
4. Horas de teoría **:** 3 por semana

1. JUSTIFICACIÓN DEL CURSO
Este curso enseña los criterios mínimos aceptables para el diseño, instalación y prueba de sistemas de Detección y Alarma de Incendio.

2. OBJETIVOS

2.1 OBJETIVO GENERAL:
Inspecciunar adecuadamente, y por otra parte, evaluar la efectividad e implementación de la selección, equipos, especificaciones, diseño, instalación, pruebas, mantenimiento y usos de los sistemas de detección y alarma contra incendio.

2.2 OBJETIVOS ESPECIFICOS:
1. Conocer la importancia de los sistemas de señalización y alarmas para la prevención de Incendios.
2. Conocer la adecuada selección, instalación, prueba, control y mantenimiento de los sistemas de alarmas y señalización.

3. CONTENIDO DEL CURSO:

3.1. Introducción y alcance y organización de la norma **norma NFPA 72**

3.2. Tipos de Sistemas, clasificación y tipos.

PROGRAMA DEL CURSO
Licenciatura en Ingeniería Mecánica con énfasis en Protección Contra Incendios

1. Nombre del Curso: SISTEMAS DE PROTECCIÓN CONTRA INCENDIOS 2
2. Sigla **:** IM-0???
3. Requisitos **:** Sistemas de Protección Contra lncendios 1
4. Horas de teoria **:** 3 por semana

1. JUSTIFICACIÓN DEL CURSO
El curso presenta los sistemas de extinción a base de rociadores, agua pulverizada espuma y neblinas para el combate de incendios que debe conocer el profesional en ingeniería de protección contra incendios. Estudio de Norma NFPA 13, 15, métodos permitidos de diseño e instalación de los SPCI por medio de rociadores automáticos, inspección y prueba de estos.

2. OBJETIVOS

2.1 OBJETIVO GENERAL:
Presentar los sistemas de supresión a base de espuma, agua pulverizada y rociadores de mayor uso en Costa Rica.

2.2 OBJETIVOS ESPECIFICOS:

1. Entender las razones de uso de otros sistemas de supresión.
2. Conocer los componentes de los sistemas: a base de espuma, agua pulverizada y rociadores, materiales y accesorios utilizados, procedimientos de selección, prueba, operación y mantenimiento.

3. CONTENIDO DEL CURSO:

3.1 Sistemas Fijos de Aspersores de Agua de Protección contra Incendios y Redes de Agua contra Incendio: La protección con agua pulverizada (NFPA 15), componentes de los sistemas de agua pulverizada, características técnicas de toberas o aspersores: Toberas comerciales y aplicaciones

3.2 SISTEMAS FIJOS DE AGUA PULVERIZADA: La protección por sistemas fijos de agua pulverizada y rociadores, materiales y accesorios utilizados, procedimientos de selección, prueba, operación y mantenimiento.

3.3 ROCIADORES: Alcance de la norma NFPA 13 de rociadores automáticos, componentes del sistema, tuberías y accesorios, tipos de sistemas (diluvio y pre-acción), métodos de instalación, tipos de rociadores posición y ubicación, rociadores especiales, otros rociadores, etc.

3.4 TIPOS DE SISTEMAS A BASE DE ESPUMA: Sistemas de espuma de baja expansión: Componentes principales, Suministro de agua, Tipos de concentrados y sus limitaciones, Métodos de proporcionamiento, Tuberías y accesorios, Sistemas fijos de espuma, Sistemas semi-fijos, Sistemas móviles, Bases y parámetros de diseño. Tipos de aplicación de espuma, Protección a tanques de almacenamiento de hidrocarburos, Requerimientos de instalación, Cálculos hidráulicos, Métodos de prueba y aceptación. Sistemas de agua-espuma a través de rociadores cerrados y boquillas abiertas, Accesorios de descarga, Concentrados de espuma y métodos de proporcionamiento, Tanques de almacenamiento, Métodos de instalación, Criterios de diseño, Duración de la descarga, sistemas húmedos, secos y de pre-acción, Cálculos hidráulicos

4. ACTIVIDADES DEL CURSO

El curso se desarrollará mediante clases magistrales, ensayos de laboratorio, visitas a instalaciones, investigación.

5. BIBLIOGRAFÍA

NFPA : Manual de Protección contra incendios
Normas NFPA l1,13,15,16
NFPA JOURNAL: artículos.

6. EVALUACIÓN

EXAMENES PARCIALES…..............55%
INFORMES DE INVESTIGACIÓN…15%
EXAMEN FINAL…..............................25%
PARTICIPACÍON…..............................5%

PROGRAMA DEL CURSO
Licenciatura en Ingeniería Mecánica con énfasis en protección contra incendios

1. Nombre del Curso: SISTEMAS DE PROTECCIÓN CONTRA INCEDIOS III

2. Sigla : IM-0???
3. Requisitos : Sistemas de Protección Conua Incendios Il
4. Horas de teoría : 3 por semana

1. JUSTIFICACIÓN DEL CURSO

El curso presenta los sistemas de extinción a base gas, polvo químico que debe el profesional en Ingeniería de Protección Contra lncendios

2. OBJETIVOS

2.1 OBJETIVO GENERAL

Presentar los sistemas de supresión a base de gas y polvo químico de mayor uso en Costa Rica.

2.2 OBJETIVOS ESPECIFICOS:

1. Entender las razones de uso de otros sistemas de supresión.
2. Conocer los componentes de los sistemas de supresión a base de gas.
3. Conocer los componentes de los sistemas de supresión a base de polvo químico

3. CONTENIDO DEL CURSO:

3.1 METODO DE INHIBICION QUIMICA.

3.2 SISTEMAS A BASE DE C02

Requisitos de concentración y tiempo de residencia, Sistemas de distribución y mecánica de fluidos, Modelos de simulación de pruebas de descarga.

3.3 SISTEMAS CON AGENTES LIMPIOS Y HALÓN

Concentración. Requisitos del contenedor y la tuberia. Toxicidad y efectos en la capa de ozono.

3.4 SISTEMAS CON POLVO QUÍMICO

Agentes, equipo de entrega, mecanismos de supresión, efectos secundarios.

3.5 PROTECCION CONTRA INCENDIOS EN EQUIPOS DE COMPUTACION.

4. ACTIVIDADES DEL CURSO

El curso se desarollará mediante clases magistmles, ensayos de laboratorio, visitas a instalaciones, investigación.

5. BIBLIOGRAFÍA

NFPA : Manual de Protección contra incendios
Normas NFPA 75 y otras.
NFPA JOURNAL: articulos

6. EVALUACIÓN

Examens Parciales.....................55%
Informes De Investigación.........15%
Examen Final.............................25%

Participación...............................5%

PROGRAMA DEL CURSO
Licenciatura en Ingeniería Mecánica con énfasis en protección contra incendios

1. Nombre del Curso: QUÍMICA 2 PARA PROTECCIÓN CONTRA INCENDIOS
2. Sigla **:** IM-0???
3. Requisitos **:** QU-0100
4. Horas de teoría **:** 3 por semana

1. JUSTIFICACIÓN DEL CURSO

Este curso complementa los conocimientos mínimos que el estudiante deberá poseer para entender adecuadamente, desde el punto de vista químico, el fenómeno de un incendio y aplicar esos conocimientos en cursos más avanzados.

2. OBJETIVOS:

2.1 OBJETIVO GENERAL
Presentar los conceptos requeridos para estudiar el incendio como una reacción química y sus efectos

2.2 OBJETIVOS ESPECÍFICOS:
Conocer las propiedades y comportamiento de materiales combustibles

1. Aplicar los conceptos de química en la selección de materiales que reduzcan el riesgo de incendio en construcción y procesos de fabricación.
2. Explicar desde el punto de vista químico daños producidos por un incendio a la vida humana y materiales.

3. CONTENIDO DEL CURSO:

3.1 Termodinámica de combustión
El Proceso de combustión, razón aire combustible, balance de masa, balance de energía.
Energia de reacción, entalpía de formación, calor de combustión, calor de reacción.
Temperatura de llama adiabática.
Combustión completa e incompleta, formación de hollín, eficiencia de combustión.

3.2 Materiales combustibles
Combustibles gaseosos, líquidos y sólidos: descripción química y procesos de combustión en ellos.
Composición química de combustibles más usuales usados como materiales de construcción o contenidos en las edificaciones: hidrocarburos, plásticos, maderas, etc.
Parámetros usados en clasificación de combustibles y grado de riesgo: punto de llama, punto de fuego, etc.

3.3 Llamas de premezcla
Estructura de llamas de premezcla. Límites de inflamabilidad, parámetros descriptivos y su medida experimental.

3.4 Mecanismos químicos de supresión de incendios

Mezclas inertes y desplazamiento de oxígeno. Enfriamiento Inhibidores de reacción en cadena. Químicos retardadores de propagación de llama.

4. ACTIVIDADES DEL CURSO:

El curso se desarrollará con clases magistrales y asignaciones de investigación. Algunos temas serán estudiados como parte de prácticas de laboratorio en un curso separado.

5. BIBLIOGRAFÍA:

A ser definida posteńormente

6. EVALUACIÓN:

EXAMENES PARCIALES..........................50%
INFORMES DE INVESTIGACIÓN............25%
EXAMEN FINAL...25%

E.2 – FULL EQUIPMENT LIST FROM UCR PACKET

Blank equipment list taken from a large packet of information that our sponsors from UCR gave us. The page numbers correspond to the number of the page within this packet. **Full list continues to next page**

PIECE OF EQUIPMENT	RELATED CODE OR STANDARD	PAGE NUMBER
Assault Nozzles	NFPA 1964	3
1" Assault nozzle		4
Improved 1.5" assault nozzle		4
1.5" Electrical assault nozzle		5
Improved mid-range assault nozzle		5
2.5" Assault nozzle		6
AKRON Saberjet Nozzles (8 styles available on page 8)	NFPA 1964, ISO 9001 registered company	
Water flow test kit	NFPA 1911, 291, or 1901	9
Hose & Apparatus Test Equipment		
The hose tester	NFPA standards (not specified)	13
Apparatus flow test kit	UL classified	13
Apparatus test guage kit		13
Gauges		
Pressure/vacuum panel adapter		14
Line gauges		14
Cap gauge		14
Pressure gauges		14
Tachometers and Flow Test Equipment		
Tachometers (hand held RPM)		15
Digital tachometer		15
Hand held pitot		15
Hydrant flow test kit	UL classified	15
Flow Test Equipment		
Large diameter kits		16
Street "T" diffuser		16
Portable flow meter		16
Fire stream/friction loss calculator		16
Micro Combustion Calorimeter		19
Flammability Tester	ASTM D 635	26
Combustion Resistance	ISO 3795, DIN 75200	27
Ignition Temperature	ASTM D 1929	28
Small Flame Reaction (mutiple setups)	CSE RF, DIN, UNI, EN-ISO	29
Test Cabinet	UL 1581	31
Flammability Tests (vertical sample)	UL 1581	41
Flammability Tests (horizontal sample)	UL 1581	41
Test assembly for flammability tests	UL 94	42
Glow Wire Flammability Test	IEC 695.21, VDE 0471 2 1	34
Silumdum Resistance	IEC 707	35
Non Combustion for Building Materials	ISO/DIS 1182.2	36

Radiant Panel		37
Apparatus for fire reaction tests at a radiant heat	ISO TC 92, CSE RF 3/77	
Radiation meter with frame	ISO TC 92, CSE RF 3/77	
Digital recorder 1 channel with display		
Accessory for general control of fire reaction testers		38
Smoke Chamber	NFPA 258-T-89, ANSI/ASTM E-662-93	39
Flue Gas Drawing System in View of Toxicity Tests	ASTM E-662	40
Oxygen Index	ASTM D 2863, ISO 4589-2	44
Optional heating attachment		45
Flammability Tester (Model 701S)	NFPA 701, CFR 1615/1616	54
Flooring Radiant Panel Tester (Model FRP-1A-CF)	NFPA 101, ASTM E 970, ASTM E 648, NFPA 253	56
Large Scale Flammability Tester (Model 701L)	NFPA 701	58
Small Scale Plastics Flammability Tester (Model GOV-94)	UL 94	60
Flammability Tester (Model TPP-2)	ASTM D 4108, ISO 9151	62
OSU Rate of Heat Release Tester		64
Single Burning Item (SBI)	EN 13823	67
Smoke measurement system		68
Burner, gas train and controls		68
Blanket Flammability Tester	ASTM D 4151	70
Radiant Panel Flame Spread Tester	ASTM E 162, ASTM D 3675	72
Smoke Density Tester	ASTM E 662, ASTM F 814, NFPA 258	74
Cone Calorimeter	ASTM E 1354, ASTM E 1740	51
Vertical Flammability Tester	FedStd. 191A, NFPA 1971 6-2, ASTM D 6413	50

E.3 - Full Equipment List Specifications

PIECE OF EQUIPMENT	Number of Accessories Required	Size	Price
AKRON Saberjet Nozzles	-	-	-
Assault Nozzles	-	-	-
Blanket Flammability Tester	N/A	Bench Scale 15"x21"x9"	N/A
Combustion Resistance	N/A	small-scale 460mmx220mmx388h	N/A
Cone Calorimeter	0	Bench-scale	$ 115,000.00
Flammability Tester	N/A	small-scale 430mmx280mmx380	N/A
Flammability Tests (horizontal sample)	N/A		$ 3,500.00
Flammability Tests (vertical sample)	N/A		$ 3,500.00
Flooring Radiant Panel Tester	0	Bench-scale	N/A
Flow Test Equipment	-	-	-
Flue Gas Drawing System in View of Toxicity Tests	N/A		N/A
Gauges	-	-	-
Glow Wire Flammability Test	1	small-scale 506mmx506mmx750mm	N/A
Hose & Apparatus Test Equipment	-	-	-
Ignition Temperature	N/A	small-scale 500mmx300x500, 700mmx500x500	N/A
Large Scale Flammability Tester (Model 701L)	N/A	bench scale 17"x98"x16"	N/A
Micro Combustion Calorimeter			
Non Combustion for Building Materials	3	Bench Scale	$ 25,829.00
OSU Rate of Heat Release Tester		bench-scale 27"x61"x__	N/A
Oxygen Index			$ 18,138.00
Protective Flammability Tester	0	small-scale 36"x_x17.5"	N/A
Radiant Panel		Bench Scale	$ 28,299.00
Radiant Panel Flame Spread Tester	1	bench scale 34"x42"x72"	$ 25,500.00
Silumdum Resistance	0	small-scale 360mmx380mmx550mm	N/A
Single Burning Item (SBI)	See Notes	Bench-Scale 3mx3mx2.6m, minimum height of 4.5m	N/A
Small Flame Reaction (mutiple setups)		small-scale 700mmx400x810h	N/A
Small Scale Plastics Flammability Tester (Model GOV-94)	0	small-scale	N/A
Smoke Chamber	4 optional	test chamber mm 1500x900x1200	$ 75,373.00
Smoke Density Tester	N/A	Bench Scale	$ 25,000.00
Tachometers and Flow Test Equipment	-	-	N/A
Test assembly for flammability tests		small-scale 1500mm x 900mm x1200mm	$ 14,500.00
Test Cabinet	10	small-scale1850mmx1310x3000h	$ 13,000.00
Vertical Flammability Tester (2)	7	Small-scale 21"x16"x32"	$3,895 (Automatic) $4,595 (Non-Automatic)
Vertical Flammability Tester (1)	7	Small-scale 21"x16"x32"	N/A

The following two pages for Appendix E.3 are the full list of specifications that were researched based upon the ENTIRE equipment list provided in the UCR packet (see Appendix E.2). This page concentrates on the physical properties as the next page concentrates on the specifications and the equipment's purpose within the lab. All information was gathered on the internet through the respective manufactures websites of The Govmark Corporation and Fire Testing Technologies Ltd.

The gray highlighted equipment was determined to have already been bought for this laboratory by Marcela Shedden and Patricio Becerra.

PIECE OF EQUIPMENT	Manufacturer	Does this piece of equipment perform fire tests?	Related Code or Standard	Prescriptive-based or performance-based	Fire Properties	Materials it can test	Relation to FPE courses
AKRON Saberjet Nozzles	Akron Brass	No	-	-	-	-	-
Assault Nozzles		No	-	-	-	-	-
Blanket Flammability Tester	Govmark	Yes	ASTM D 4151	Prescriptive	Ignitability	Blankets	Chemistry 2 for FPE, Fire Dynamics
Combustion Resistance	Fire Testing Technology Ltd	Yes	ISO 3795, DIN 75200	Prescriptive	Resistance to combustion	Parts located inside automotives	Chemistry 2 for FPE, Fire Dynamics
Cone Calorimeter	Govmark	Yes	ASTM E 1354, ASTM E 1740, ASTM E 1550, ASTM D 5485, ASTM D 6113, NFPA 271, NFPA 264, ISO 5660 Parts 1 and 2	Both	Ignitability, Smoke production (amount), Mass loss, Heat and Smoke release rates, Heat of Combustion, Average Specific Extinction Area	Plastics, composites, wood, laminates	Chemistry 2 for FPE, Fire Dynamics, Risk Analysis
Flammability Tester	Fire Testing Technology Ltd	Yes	ASTM D 635	Prescriptive	Rate of Burning	Rigid plastic specimens	Fire Dynamics
Flammability Tests (horizontal sample)	Fire Testing Technology Ltd	Yes	ASTM D1532, ASTM EI321-09, ASTM D 5025	Prescriptive	Flame resistance, Ignition, Flame Spread	Textiles and plastics	Chemistry 2 for FPE, Fire Dynamics
Flammability Tests (vertical sample)	Fire Testing Technology Ltd	Yes	ASTM D6413, ASTM D 5025	Prescriptive	Flame resistance, Ignition, Flame Spread	Textiles and plastics	Chemistry 2 for FPE, Fire Dynamics
Flooring Radiant Panel Tester	Govmark	Yes	ASTM E 648, NFPA 253, ISO 9239-1	Prescriptive	Critical radiant flux at flameout	Carpeting and flooring materials used in public buildings and public transportation, attic insulation	Fire Dynamics
Flow Test Equipment		No	-	-	-	-	-
Flue Gas Drawing System in View of Toxicity Tests	Fire Testing Technology Ltd	Yes	ASTM E-662	Performance	Flue gas drawing for gas-chromatographic analysis	Smoke	Risk Analysis
Gauges		No	-	-	-	-	-
Glow Wire Flammability Test	Fire Testing Technology Ltd	Yes	IEC 695.21, VDE 0471 2 1	Prescriptive	Flammability	Materials used for fabrication of electronic components	Chemistry 2 for FPE
Hose & Apparatus Test Equipment		No	-	-	-	-	-
Ignition Temperature	Fire Testing Technology Ltd	Yes	ASTM D 1929	Prescriptive	Ignition and self ignition temperature	Plastic Materials	Chemistry 2 for FPE, Fire Dynamics
Large Scale Flammability Tester (Model 701L)	Govmark	Yes	NFPA 701, UL 214, CAN/ULC S109	Prescriptive	Ignition resistance	Draperies, cubic curtains, outdoor products, banners	Fire Dynamics
Micro Combustion Calorimeter	BOUGHT	Yes		Prescriptive	Flammability, Fire Load, Ignition Temperature, Heat Release Rate, Flame Resistance	Plastics, wood, clothing, etc.	Chemistry 2 for FPE, Fire Dynamics
Non Combustion for Building Materials	Fire Testing Technology Ltd	Yes	ISO/DIS 1182.2	Prescriptive	Fire Reaction	Building Materials	Chemistry 2 for FPE
OSU Rate of Heat Release Tester	Govmark	Yes	FAR Part 25 Appendiz F Part IV, Boeing BSS 7322, Airbus AITM 2.0006	Performance	Heat Release Rate	Aircraft Interior Materials	Risk Analysis
Oxygen Index	Fire Testing Technology Ltd	Yes	ASTM D 2863, ISO 4589-2	Percriptive	Oxygen Index	Measure the 02 and N2 in a gas mixture	None
Protective Flammability Tester	Govmark	Yes	EN ISO 1182, EN ISO 1716, EN ISO 11925-2	Both	Thermal performance properties when exposed to high heat source	Materials used in protective clothing	None
Radiant Panel	Fire Testing Technology Ltd	Yes	ISO TC 92	Prescriptive	Fire Reaction, Flammability	Coating materials for walls, floors, ceilings and furniture	Chemistry 2 for FPE, Fire Dynamics
Radiant Panel Flame Spread Tester	Govmark	Yes	ASTM E 162, ASTM D 3675	Prescriptive	Flame spread, Flammability	Textiles, plastics, foam and similar materials used in furnishings, building products and transportation materials	Chemistry 2 for FPE, Fire Dynamics
Silumdum Resistance	Fire Testing Technology Ltd	Yes	IEC 707	Prescrtiptive	Burning rate, Burning time, Extent of burning	Rigid plastics	Fire Dynamics
Single Burning Item (SBI)	Fire Testing Technology Ltd	Yes	EN ISO 1182, EN ISO 1716, EN ISO 11925-2	Both	Fire Reaction, Heat and Smoke Release Rate	Building materials (excluding flooring)	Chemistry 2 for FPE, Fire Dynamics
Small Flame Reaction (mutiple setups)	Fire Testing Technology Ltd	Yes	CSE RF, DIN, UNI, EN-ISO	Prescriptive	Fire Reaction	Materials normally used in furnishing and building	Chemistry 2 for FPE
Small Scale Plastics Flammability Tester (Model GOV-94)	Govmark	Yes	UL 94HB, UL 94HBF, UL 94HF, UL 94V, UL94 VTM, UL 945V, ISO 1210, IEC 60695-11-10, IEC 60695-16-20, ASTM D635, ASTM D3801	Perscriptive	Burning properties of plastic materials	Plastics	Fire Dynamics
Smoke Chamber	BOUGHT	Yes	NFPA 258-T-89, ANSI/ASTM E-662-93, BSS-18, BS 6401	Prescriptive	smoke density from combustion of plastics,	Plastics	Risk Analysis
Smoke Density Tester	Govmark	Yes	ASTM E 662, ASTM F 814, NFPA 258	Undetermined	Smoke measurements of burning materials, Specific optical density under flaming and non-flaming, used for extraction of toxic gas	Solid materials	Risk Analysis
Tachometers and Flow Test Equipment		No	-	-	-	-	-
Test assembly for flammability tests	Fire Testing Technology Ltd	Yes	UL 94	Prescriptive	Flammability	Plastics	
Test Cabinet	Fire Testing Technology Ltd	No	-	-	-	-	-
Vertical Flammability Tester (2)	Govmark	Yes	FedStd. 191A, NFPA 1971 6-2, ASTM D 6413	Prescriptive	Ignition resistance	Aircraft and transportation materials, tents and protective clothing	Fire Dynamics
Vertical Flammability Tester (1)	Govmark	Yes	NFPA 701 (1989), CPAI 84, CAN/ULC S109, UL 214, CA TB 117 AI and B, CA Title 19, 16 CFR 1615 and 1616	Prescriptive	Ignition resistance	Draperies, cubicle curtains, children's sleepwear, upholstery foams and tents	Fire Dynamics

E.4 - NARROWED EQUIPMENT LIST WITH RESEARCHED SPECIFICATIONS

The following table is the equipment we researched specifications on. Many items were taken off the original list Appendix E.2 as they were irrelevant to the scope of our project. Only fire-testing equipment was researched. This information was then used to conduct the qualitative analysis and the quantitative analysis.

PIECE OF EQUIPMENT	Manufacturer	Standards	Fire Properties	Relevant Courses	Materials it tests
Blanket Flammability Tester	Govmark	ASTM D 4151	Ignitability	Chemistry 2 for FPE, Fire Dynamics	Blankets
Cone Calorimeter	Govmark	ASTM E 1354, ASTM E 1740, ASTM E 1550, ASTM D 5485, ASTM D 6113, NFPA 271, NFPA 264, ISO 5660 Parts 1 and 2	Ignitability, smoke production (amount), mass loss, heat and smoke release rates, heat of combustion, average specific extinction area	Chemistry 2 for FPE, Fire Dynamics, Risk Analysis	Plastics, composites, wood, laminates
Flammability Tester	Fire Testing Technology Ltd	ASTM D 635, IEC 65	Rate of burning	Fire Dynamics	Rigid plastic specimens
Flammability Tests (horizontal sample)	Fire Testing Technology Ltd	ASTM D 5132-04	Horizontal flame resistance	Chemistry 2 for FPE, Fire Dynamics	All materials
Flammability Tests (vertical sample)	Fire Testing Technology Ltd	ASTM D 6413-08	Vertical flame resistance	Chemistry 2 for FPE, Fire Dynamics	All materials
Ignition Temperature	Fire Testing Technology Ltd	ASTM D 1929	Ignition temperature	Chemistry 2 for FPE, Fire Dynamics	Plastic Materials
Non Combustion for Building Materials	Fire Testing Technology Ltd	ISO/DIS 1182.2	Fire Reaction	Chemistry 2 for FPE, Fire Dynamics	Building Materials
Radiant Panel	Fire Testing Technology Ltd	ISO TC 92	Fire Reaction, Flammability	Chemistry 2 for FPE, Fire Dynamics	Coating materials for walls, floors, ceilings and furniture
Radiant Panel Flame Spread Tester	Govmark	ASTM E 162, ASTM D 3675, UL 94	Flame spread	Fire Dynamics	Textiles, plastics, foam and similar materials used in furnishings, building products and transportation materials
Single Burning Item (SBI)	Fire Testing Technology Ltd	EN ISO 1182, EN ISO 1716, EN ISO 11925-2	Reaction of fire, heat and smoke release rate	Chemistry 2 for FPE, Fire Dynamics	Building materials (excluding flooring)
Small Scale Plastics Flammability Tester (Model GOV-94)	Govmark	ASTM D635, ASTM D3801, ASTM D 4986, ISO 1210, ISO 9772, ISO 9773, UL 94	Flammability	Fire Dynamics	Plastics
Smoke Density Tester	Govmark	ASTM E 662, ASTM F 814, NFPA 258, ISO 5659-2	Smoke measurements of burning materials: Specific optical density under flaming and non-flaming, used for extraction of toxic gas	Risk Analysis	All materials
Test assembly for flammability tests	Fire Testing Technology Ltd	ASTM E-1312-09	Ignition and flame spread	Chemistry 2 for FPE, Fire Dynamics	All materials

APPENDIX F: EQUIPMENT ANALYSIS TOOLS ITEMS

F.1 - BLANK QUALITATIVE ANALYSIS TOOL

PIECE OF EQUIPMENT	Manufacturer	Does this equipment support prescriptive tests?	Does it use ASTM or ISO standards?	Does it test materials on the list?	Does it support any FPE courses?	Designated Level (Pass or Eliminate)
Blanket Flammability Tester	Govmark					
Combustion Resistance	Fire Testing Technology Ltd					
Cone Calorimeter	Govmark					
Flammability Tester	Fire Testing Technology Ltd					
Flooring Radiant Panel Tester	Govmark					
Glow Wire Flammability Test	Fire Testing Technology Ltd					
Ignition Temperature	Fire Testing Technology Ltd					
Large Scale Flammability Tester (Model 701L)	Govmark					
Non Combustion for Building Materials	Fire Testing Technology Ltd					
OSU Rate of Heat Release Tester	Govmark					
Oxygen Index	Fire Testing Technology Ltd					
Protective Flammability Tester (Model TPP-2)	Govmark					
Radiant Panel	Fire Testing Technology Ltd					
Radiant Panel Flame Spread Tester	Govmark					
Silumdum Resistance	Fire Testing Technology Ltd					
Single Burning Item (SBI)	Fire Testing Technology Ltd					
Small Flame Reaction (mutiple setups)	Fire Testing Technology Ltd					
Small Scale Plastics Flammability Tester (Model GOV-94)	Govmark					
Smoke Density Tester	Govmark					
Flammability Tests (horizontal sample)	Fire Testing Technology Ltd					
Flammability Tests (vertical sample)	Fire Testing Technology Ltd					
Test assembly for flammability tests	Fire Testing Technology Ltd					
Vertical Flammability Tester (1)	Govmark					
Vertical Flammability Tester (2)	Govmark					

**We devised this table to qualitatively analyze each piece of equipment in preparation for the quantitative analysis. Yes or No would be answered within the table. Those that answered yes to all questions would pass on whereas those that did not were eliminated. The completed qualitative analysis is shown next in Appendix F.2

F.2 - Filled in Qualitative Analysis

PIECE OF EQUIPMENT	Manufacturer	Does this equipment support prescriptive tests?	Does it use ASTM or ISO standards?	Does it test materials on the list?	Does it support any FPE courses?	Designated Level
Blanket Flammability Tester	Govmark	Yes	Yes	Yes	Yes	Pass
Combustion Resistance	Fire Testing Technology Ltd	Yes	Yes	No	-	Eliminate
Cone Calorimeter	Govmark	Yes	Yes	Yes	Yes	Pass
Flammability Tester	Fire Testing Technology Ltd	Yes	Yes	Yes	Yes	Pass
Flooring Radiant Panel Tester	Govmark	Yes	Yes	No	-	Eliminate
Glow Wire Flammability Test	Fire Testing Technology Ltd	Yes	No	-	-	Eliminate
Ignition Temperature	Fire Testing Technology Ltd	Yes	Yes	Yes	Yes	Pass
Large Scale Flammability Tester (Model 701L)	Govmark	Yes	No	-	-	Eliminate
Non Combustion for Building Materials	Fire Testing Technology Ltd	Yes	Yes	Yes	Yes	Pass
OSU Rate of Heat Release Tester	Govmark	No	-	-	-	Eliminate
Oxygen Index	Fire Testing Technology Ltd	Yes	Yes	No	-	Eliminate
Protective Flammability Tester (Model TPP-2)	Govmark	Yes	Yes	No	-	Eliminate
Radiant Panel	Fire Testing Technology Ltd	Yes	Yes	Yes	Yes	Pass
Radiant Panel Flame Spread Tester	Govmark	Yes	Yes	Yes	Yes	Pass
Silumdum Resistance	Fire Testing Technology Ltd	Yes	No	-	-	Eliminate
Single Burning Item (SBI)	Fire Testing Technology Ltd	Yes	Yes	Yes	Yes	Pass
Small Flame Reaction (mutiple setups)	Fire Testing Technology Ltd	Yes	No	-	-	Eliminate
Small Scale Plastics Flammability Tester (Model GOV-94)	Govmark	Yes	Yes	Yes	Yes	Pass
Smoke Density Tester	Govmark	Yes	Yes	Yes	Yes	Pass
Flammability Tests (horizontal sample)	Fire Testing Technology Ltd	Yes	Yes	Yes	Yes	Pass
Flammability Tests (vertical sample)	Fire Testing Technology Ltd	Yes	Yes	Yes	Yes	Pass
Test assembly for flammability tests	Fire Testing Technology Ltd	Yes	Yes	Yes	Yes	Pass
Vertical Flammability Tester (1)	Govmark	Yes	No	-	-	Eliminate
Vertical Flammability Tester (2)	Govmark	Yes	Yes	No	-	Eliminate

This tool was filled in by our group using the details from the specification list seen in Appendix E.3

F.3 - *CAR AND DRIVER MAGAZINE*: EXAMPLE QUANTITATIVE ANALYSIS

FINAL RESULTS

RANK	Maximum points available	1	2	3	4	5
		Porsche 911 Turbo S	Ferrari 458 Italia	Audi R8 5.2 FSI	Mercedes-Benz SLS AMG	Aston Martin V-12 Vantage
VEHICLE						
DRIVER COMFORT	10	8	8	9	8	9
ERGONOMICS	10	8	7	9	9	6
REAR-SEAT SPACE*	5	2	–	–	–	–
CARGO SPACE*	5	5	4	3	3	5
FEATURES/AMENITIES*	10	10	8	8	9	6
FIT AND FINISH	10	9	8	9	8	9
INTERIOR STYLING	10	7	9	9	8	9
EXTERIOR STYLING	10	7	10	8	8	9
REBATES/EXTRAS*	5	0	0	0	0	0
AS-TESTED PRICE*	20	20	7	19	15	16
SUBTOTAL	**95**	**76**	**61**	**74**	**68**	**69**
POWERTRAIN						
1/4-MI ACCELERATION*	20	20	17	14	16	12
FLEXIBILITY*	5	3	4	4	3	4
FUEL ECONOMY*	10	10	5	7	6	7
ENGINE NVH	10	8	9	8	9	9
TRANSMISSION	10	9	10	8	8	8
SUBTOTAL	**55**	**50**	**45**	**41**	**42**	**40**
CHASSIS						
PERFORMANCE*	20	19	19	19	18	17
STEERING FEEL	10	9	10	8	8	8
BRAKE FEEL	10	9	9	8	8	8
HANDLING	10	9	10	8	9	7
RIDE	10	8	9	9	8	7
SUBTOTAL	**60**	**54**	**57**	**52**	**51**	**47**
EXPERIENCE						
FUN TO DRIVE	25	21	25	20	21	19
GRAND TOTAL	**235**	**201**	**188**	**187**	**182**	**175**

This picture was taken from *Car and Driver* online. It shows an example of a quantitative analysis tool. *Car and Driver* ranks cars using this system and it was the basis for our quantitative analysis tool

Source:
http://www.caranddriver.com/var/ezflow_site/storage/original/application/f402b130222e6f98ef15ba1165617301.pdf

F.4 - SPONSOR RATINGS OF FACTORS FOR QUANTITATIVE ANALYSIS

DIRECTIONS: For us to understand your specific needs for fire-testing equipment, we would like you to rank the following characteristics. Please use the scale 1-5, where 5 is the most important to you and 1 is of least importance to you. You can only use two of each number ratings; this means that you can only use two 5's, two 4's, two 3's and so on. We will be using these ratings to do our quantitative analysis. ***Also, there are two sub-sections which require a rating. Directions are given in the respective sub-sections.

Performance Characteristics

--5-- Fire Courses

- Amount of classes equipment can supplement

--4-- Materials

- Amount of materials that equipment tests

--4-- Standards

- Amount of standard test methods equipment supports
- Variety of standard test methods that can be performed

--5-- Fire Properties

- Amount of fire properties equipment can measure

~~**--3--** Sample Size~~

~~- Size of sample that equipment requires (2=more important; 1=less important)~~

~~**-2--** Larger (visible sample)~~ ~~**--1--** Smaller (micro sample)~~

~~Physical Specification Characteristics~~

~~**--1--** Price of Equipment~~

~~-Total Price including necessary accessories (installation not included)~~

~~**--2--** Size of Equipment~~

~~- Physical dimensions (2=more important; 1=less important)~~

~~**--1--** Larger (Floor Model)~~ ~~**--2--** Smaller (Bench Model)~~

~~**--3--** Accessories Needed~~

~~- Amount of accessories needed for full operation~~

~~- Accessories already present in the laboratory~~

******All strike through factors are ones that Marcela and Patricio did not want us to consider when performing the quantitative analysis******

F.5 - Blank Quantitative Analysis Tool

This is the blank quantitative analysis tool that we developed for ranking the equipment. The final filled out analysis can be seen in Appendix F.7

PIECE OF EQUIPMENT	Manufacturer	Fire Courses	Standards	Materials	Fire Properties	FINAL TOTAL
Rating Description	-	# of courses equipment can supplement	# of standard test methods equipment supports	# of relevant materials that can be tested	# of fire properties equipment measures	-
Maximum Points	-	25	20	20	25	90
Cone Calorimeter	Govmark					0
Single Burning Item (SBI)	Govmark					0
Radiant Panel Flame Spread Tester	Fire Testing Technology Ltd					0
Radiant Panel	Fire Testing Technology Ltd					0
Flammability Tests (horizontal sample)	Fire Testing Technology Ltd					0
Flammability Tests (vertical sample)	Fire Testing Technology Ltd					0
Non Combustion for Building Materials	Fire Testing Technology Ltd					0
Smoke Density Tester	Govmark					0
Ignition Temperature	Govmark					0
Small Scale Plastics Flammability Tester (Model GOV-94)	Fire Testing Technology Ltd					0
Blanket Flammability Tester	Govmark					0
Flammability Tester	Fire Testing Technology Ltd					0

F.6 - Rubric for filling out Quantitative Analysis

The following is the rubric which we created for systematically doing the quantitative analysis

<u>Quantitative Rubric</u>

Fire Courses:

- 3 courses = 25 points
- 2 courses = 15 points
- 1 course = 5 points

Standards:

- 1 standard = 3 points
- 2 standards = 7 points
- 3 standards = 10 points
- 4 standards = 13 points
- 5 standards = 17 points
- 6 standards = 20 points

Fire Properties:

- 1 property = 3 points
- 2 properties = 6 points
- 3 properties = 10 points
- 4 properties = 13 points
- 5 properties = 17 points
- 6 properties = 21 points
- 7 properties = 25 points

Materials:

- 1 specific type of material= 3 points
- 1 specific category of material (i.e. plastics) = 7 points
- 2-3 types of materials = 10 points
- 4-6 types of materials = 17 points
- 1 general category of materials (i.e. building materials) = 15 points
- “All” = 20 points

F.7 - Quantitative Analysis Result

PIECE OF EQUIPMENT	Manufacturer	Fire Courses	Standards	Materials	Fire Properties	FINAL TOTAL
Rating Description	-	# of courses equipment can supplement	# of standard test methods equipment supports	# of relevant materials that can be tested	# of fire properties equipment measures	-
Maximum Points	-	25	20	20	25	90
Cone Calorimeter	Govmark	25	20	17	25	87
Single Burning Item (SBI)	Govmark	15	10	15	10	50
Radiant Panel Flame Spread Tester	Fire Testing Technology Ltd	15	7	17	6	45
Radiant Panel	Fire Testing Technology Ltd	15	3	15	6	39
Flammability Tests (horizontal sample)	Fire Testing Technology Ltd	15	3	10	10	38
Flammability Tests (vertical sample)	Fire Testing Technology Ltd	15	3	10	10	38
Non Combustion for Building Materials	Fire Testing Technology Ltd	15	3	15	3	36
Smoke Density Tester	Govmark	5	2	20	6	33
Ignition Temperature	Govmark	15	3	7	6	31
Small Scale Plastics Flammability Tester (Model GOV-94)	Fire Testing Technology Ltd	5	10	7	3	25
Blanket Flammability Tester	Govmark	15	3	3	3	24
Flammability Tester	Fire Testing Technology Ltd	5	3	3	3	14