Engineering Educators Bringing the World Together
2025 ASEE Annual Conference & Exposition
Palais des congrès de Montréal, Montréal, QC • June 22–25, 2025 ASEE
Paper ID #46771

An Elective Course in Chemical Process Safety: Managing and Responding to Hazardous Incidents

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Introduction

In 2005, two alumni members of the chemical engineering department's industrial advisory council at Missouri University of Science and Technology worked together to offer a noncredit course based on OSHA's hazardous waste and emergency response (HAZWOPER) training requirements. This was well received by the 12 students who attended, and it was suggested that this be redesigned as a full credit course with a traditional lecture portion that could focus on the technical side of the response such as dispersion modeling and hazard recognition. This became the Hazardous Materials Management course that is currently offered annually, teaching students how hazardous materials emergencies are managed and contained.

The concept of emergency response is presented in an enjoyable and exciting manner, offering students something new and significantly different compared to their foundational courses. The opportunity to work in encapsulated PPE, use self-contained breathing apparatus, and manipulate advanced field instruments is well received. However, the true focus of the course is to prepare new engineers for professional practice. This is done first through the understanding of models for good problem solving and good decision making. Engineers are taught problem solving techniques throughout their foundational instruction; however, most students do not appreciate the skill of good problem solving nor the tools that can be applied to complex problems. This course demonstrates problem-solving techniques that can be applied equally to emergencies or typical engineering problems. This then leads to understanding the consequences of bad problem solving or poor decision making. Few chemical engineers will enter the world of emergency response; however, most engineers will make multiple decisions and design many processes that have the potential to lead to a significant hazardous materials event. Understanding the response required helps these future engineers fully appreciate the advantages of sound decision making and problem solving. Finally, the course reinforces the fundamentals of chemical engineering through real life application. Throughout the course, students apply organic and physical chemistry, thermodynamics, fluid dynamics, and heat transfer principles. Students also apply personal and process safety principles, as well as environmental protection principles. All this application occurs in an exciting, novel experience that is uniquely different from engineering foundational courses.

Course Structure and Semester Schedule

The Hazardous Materials Management course has two components. The first is two weekend activities where students respond to three simulated emergencies. In the first weekend, one day is dedicated to covering the necessary instructional material including types of hazards, the incident command structure, resources available to response management, and the type and operation of equipment used in emergency response which includes live demonstrations. Students are given a chance to volunteer for roles in the command structure for the simulation on the second day. At the start of second day, the simulation (Simulation #1) is set up, students are informed of their role for the emergency response, and the response begins. Once the activity is completed and broken down, the instructors discuss the response with the students, giving opportunities to find what went well and what could be improved.

The second weekend includes a morning lecture on advanced topics, a simulated emergency (Simulation #2) in the afternoon of the first day, and the final activity (Simulation #3) the second day. Students are also instructed to conceptualize a local emergency and develop a response to it, using the principles taught in the course. These are presented throughout the weekend, and alumni instructors provide feedback on their responses for students to address before a final presentation to the faculty instructor and the class.

The second component of the course is weekly lectures presented by the faculty instructor. Much of the material is covered in the first weekend meeting; however, the weekly lectures give students a second look at the material and serves as a reminder of what they should consider in their conceptualized response. This also gives them a chance to ask questions they may have developed since the first weekend activity as well as giving the faculty a chance to discuss the material more in depth as they see fit.

The course is scheduled to meet twice per week. For most of the semester, the second day is reserved for student teams to meet and develop their response to their conceptualized emergency. This dedicates time for the instructor to be available for questions. Depending on the availability of industrial partners, they may also be available for questions, but students are reminded that a professional work schedule may prohibit timely responses. After both weekend activities, a discussion is held in lecture for students to further analyze what went well, what could be improved, what they were impressed by, or what surprised them most. This was last done by the instructor grouping students together to discuss questions the instructor had generated during the weekend activities. Once individual groups had discussed the question, they were invited to share with the class. In past semesters, this was done instead as a discussion board on Canvas; however, instructors felt that an in-class approach would lead to better discussion. Near the end of the semester, students present their conceptualized emergency and response to the class. This takes place after the second weekend activity so feedback from industry partners can be incorporated.

Students are told the team assignment may take the form of a traditional presentation or may be filmed as a newscast. Regardless of form, the chemical(s), hazards, hot zone, and evacuation points must be identified. Symptoms of exposure must be found and conveyed as well as a location for emergency medical treatment. Students must also develop an overall response strategy including the appropriate level of PPE, decontamination details, and specific containment or mitigation details. Projects include material behavior prediction, including vapor dispersion modeling and the effects of meteorological / terrain conditions on the emergency.

Grades for the course are assigned in three groups. Attendance in the weekend activities is mandatory as well as in the discussion the following week. If students are unavailable for the discussion, they can instead write a short report on their experience that weekend. Half of a student's grade is tied to team creation and conceptual emergency, their emergency response presentation, and evaluation of other teams. Finally, students are instructed to find four different hazmat transportation placards in town or while traveling and use the Emergency Response Guidebook (ERG) to both learn about the chemical and complete an initial evaluation of how to respond to a release. Students must identify the chemical; potential hazards; public safety including protective clothing, evacuation, fire, and first aid; initial isolation and protective distances; and whether the chemical reacts with water and forms a toxic gas. This is due by the end of the semester.

The first weekend activity typically occurs in the first weekend of the semester. This, combined with a lecture the second week detailing the requirements of the conceptualized emergency, provides student with enough information to complete their project. As stated, lecture topics largely review the material from the first weekend, so the first activity needs to occur early in the semester. The second weekend takes place at the end of week twelve of a fifteen-week semester. This gives enough time for students to incorporate feedback on their response before presenting again to the instructor and class in week fourteen. Apart from the placard assignment, the presentations conclude the semester, and class does not meet in the last week. Given the length and value of the weekend activities, this is not considered value lost.

Simulated Emergencies

Three simulated emergencies are used in the class to provide a challenging, progressive problem-solving experience. The scenarios used are unique and interesting, holding the students' attention. The simulations are designed to be realistic, limited by typical constraints, and require little imagination or pretending. For example, a leaking pipe emergency using water as a surrogate chemical presents students with an actual fluid under pressure, creating all the typical challenges faced by first responders such as limited movement from protective equipment and communication difficulty.

Simulation #1

The first simulation allows students to apply the incident command system, use typical personal protective equipment (PPE), construct and operate a two-stage decontamination system, and use basic field instrumentation. The command team prepares an incident action plan, consistent with the requirements of OSHA's 29 CFR 1910.120 [1], based on details provided in real-time. The team's public information officer conducts three on-camera interviews, interfacing with a reporter played by an instructor.

Students learn to operate within Level A PPE – a fully encapsulated chemical-resistant suit, chemical resistant boots and gloves, and self-contained breathing apparatus (SCBA). Students utilize two-way radios, colorimetric gas detection tubes, and a 4-gas/photoionization detector (PID) to help identify and characterize the emergency.

The scenario involves repairing two different leaks on a 1 ½" PVC piping system. One leak is due to a damaged gasket in a piping flange; the second leak is a pair of holes drilled into the pipe. Students are given a short course in pipe fitting techniques covering how to change a flange gasket and how to utilize band clamps to seal a hole. During the scenario, the piping assembly is connected to a garden hose and is pressurized with water, allowing the responders to affect the repairs under more realistic conditions. The decontamination team is taught proper techniques to execute technical decontamination of responders in PPE. Students participating in the safety team are taught to measure vital signs (pulse, respiration rate, and blood pressure) for team members utilizing PPE/SCBA. These students are reminded that a person's health records are protected information and should not be shared.

The commodity simulated, anhydrous hydrofluoric acid, is presented in the form of a DOT (Department of Transportation) placard. Students must identify the placard code and use available reference materials (safety data sheet, DOT Emergency Response Guidebook, and the NIOSH (National Institute for Occupational Safety and Health) Pocket Guide) to characterize the commodity. Additionally, the student command team must determine downwind isolation and evacuation distances, appropriate neutralizing agents, and tactical plan sequencing to mitigate the leaks.

Simulation #2

The second simulation creates a more challenging problem-solving environment. The scenario involves an illicit drug lab with an unconscious victim. The student team is only given vague details about potential potent drug exposure and are informed that a student is missing. Level B

PPE is used to slightly reduce the physical hindrances, allowing students to focus more on problem solving.

The tactical team is taught victim recovery and decontamination techniques which they realize are needed when they discover their unconscious (simulated) classmate. Despite being taught victim decontamination, some teams remain anchored to their first simulation and fail to make entry with tools needed for victim transport. The tactical team must also sample a combination of powders and pills (typically intact and powdered caffeine tablets) and transfer these materials to the command team. Teams often remain anchored to typical laboratory sampling and realize that different techniques are required when they try to sample wearing multiple glove layers and an SCBA.

In addition to building on the incident action plan and overall mitigation solution introduced in the first simulation, students must identify the unknown materials recovered from the hot zone. Ruggedized Infrared, Raman, and mass spectrometers are used by the command team, allowing students to apply their analytical skills using actual person-portable instruments. The specific instruments are those utilized routinely by emergency responders and provide students with an opportunity to experience the technological advances made in analytical equipment.

Simulation #3

The final exercise focuses on team dynamics and communication. The class is separated into two teams – the tactical team, which selects two two-person entry teams with the remainder of the group as support staff; and the command team, which designates an incident commander and communications officer, with the remainder of the team as a brainstorming group. Using limited PPE (SCBA, acid hood, and gloves), the tactical team is presented with a series of threaded pipe pieces, valves, and piping unions. The command team, separated from the tactical team, is presented with a piping schematic that uses some (but not all) piping pieces. The command team must sequentially talk the tactical team through construction of the schematic without being able to visually observe the work being performed.

This exercise creates challenges with dexterity (manipulating piping with heavy gloves and limited visibility), communication (radio use while using SCBA), and solution sequencing (assembling the correct parts in the correct order). Additionally, students discover during the exercise that their team's assumptions may not match the other team's reality. For example, command teams typically assume the only parts presented to the tactical team are the exact parts on the schematic. The tactical team, not seeing the schematic, assumes the command team is aware of all the parts presented. This activity also gives students an appreciation of good design and forethought. For example, the assembly order may prevent a valve from rotating without colliding into a previously assembled pipe.

The three simulations successively build on skills introduced in classroom instruction and previous simulations. Throughout the simulations, students are shown how problem-solving techniques they are applying in emergencies parallel techniques used in typical (non-emergency) engineering problem solving. One way this is done is the concept of identify-characterize-control (ICC), taught as the basis for problem solving in the classroom. This gives students a deeper understanding of the problem-solving process which is often used in professional practice for root cause problem solving or variability reduction. A benefit of this process is seen in the control phase of problems solving. Classroom problems tend to give problems with one solution. The emergency simulations reinforce the idea that engineering problems are often open-ended, that solutions are often desired operating ranges, equipment sizes, or other abstract solutions rather than a singular definitive answer.

Incident Command System

Students are taught the Incident Command System (ICS) [2], a model widely adapted by emergency responders for managing any incident, from a single house fire to a large multi-state disaster. ICS is a core component of the United States National Incident Management System [3]. This model is a hierarchal, modular organization system designed to be adaptable to a wide range of applications. For many students, this is their first exposure to formal hierarchical delegation.

The ICS identifies an incident commander (IC), the ultimate decision authority for the incident. The IC uses a combination of staff positions and branch leaders to manage the emergency. The modular design of ICS allows the system to be adjusted to meet the scope of the incident. The model used in this course is shown in Figure 1.

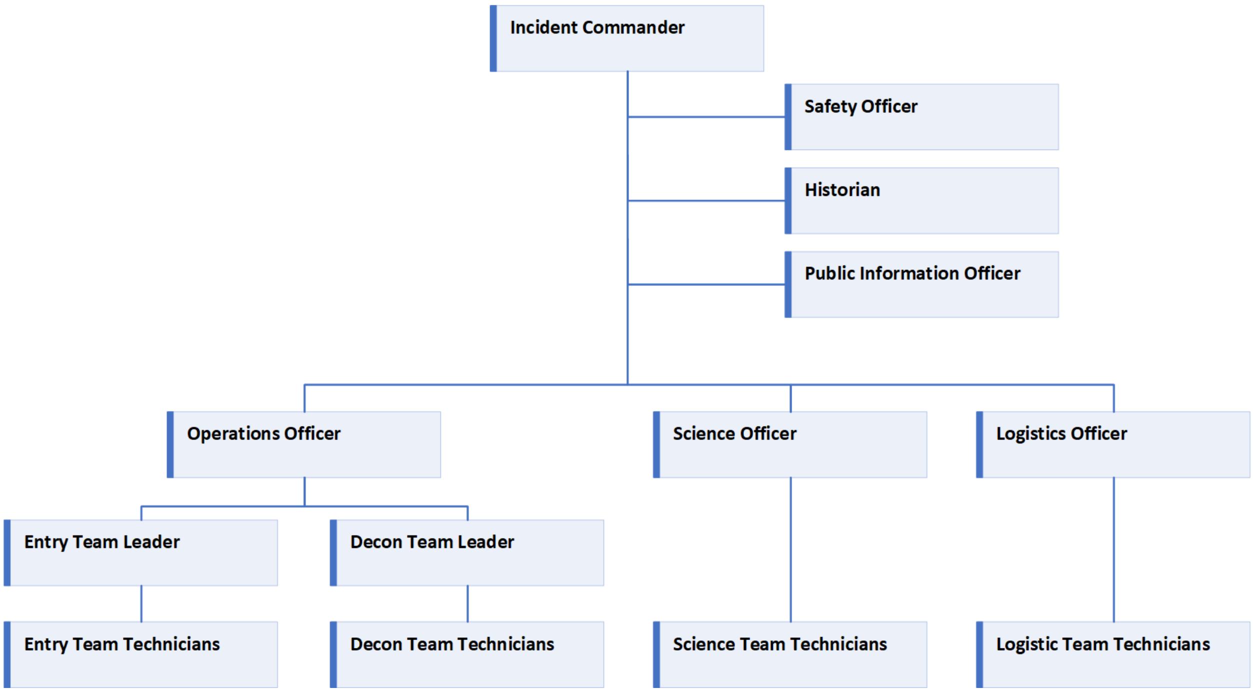

Figure 1: HAZMAT Incident Command System utilized in the simulated emergency responses

The historian is responsible for keeping a written record of all decisions, communications, and discussions as well as major points during the response. Should the worst or unexpected happen, this record is the responders' defense regarding actions taken. As such, students are reminded that this record should not be short, and that the historian must be diligent and attentive. Due to their role of recording the event, the historian is well prepared to step in as IC should something happen to their predecessor.

The safety officer is responsible for the real-world hazards associated with the simulated response. They monitor time responders are in PPE and using air from SCBA, enforce a hard 20-minute stop to ensure responders have an adequate breathing air reserve, and ensure the overall safety of the area and responders. The safety officer has the authority to stop the simulation if any safety issue arises. Two medical officers report to the safety officer who are responsible for monitoring the vital signs of the entry and decon teams. The medical officers are trained before the response on how to take blood pressure readings and check pulse and respiration rates. In addition to charging the student safety officer with real-time safety, both alumni instructors are trained emergency responders and function as an additional layer of protection for overall student safety.

The public information officer (PIO) is the public face of the organization attached to the emergency and interfaces with the media. During the response, the PIO is interviewed two or three times by one of the instructors taking the role of a reporter. These interviews are recorded and played back to the class as part of the post-activity evaluation and discussion. It is the PIO's responsibility to get a consistent message to the public which can include evacuation zones, evacuation locations, and treatment if someone suspects they are contaminated. The challenge of this role is to make the responders sound as competent as they are and allay public fears while controlling the media message. Students are taught the media message is a core component to the incident response, not just a conveyance information.

The operations officer is the liaison between the command staff and the response group, serving as the tactical leader for the response. They are responsible for communications between the two groups, as well as the go-to person for questions. They oversee the response plan implementation. Reporting to the operations officer are the entry and decontamination team leaders, who are responsible for directing their teams in the specific tasks they will perform.

The entry team is responsible for executing the devised plan and consists of two teams of two responders. They enter the hot zone where the incident is occurring and perform tasks to mitigate the incident. One team will enter the area and perform one task, and when complete, the second will do the same. Backup teams, or rapid intervention teams (RIT), are simulated to ensure both teams can perform roles and complete tasks. The decontamination team of four is responsible for setting up and breaking down the decontamination corridor and removing any hazardous chemicals from the entry team's suits so they may safely doff their PPE. The decon team is supported by the logistics team and others who are available.

A challenge for each of these teams is to avoid common maneuvers or postures that can create additional hot zone hazards. For example, it is reflexive for someone to kneel when working on something low to the ground. This action can easily scuff or rupture a suit, putting that responder in danger. The decontamination area is a rectangle where each face has significance. The entry team may enter contaminated from the west and leave clean to the east. The decontamination team must stay on their clean side (say the north) while cleaning the entry team, to minimize contaminating themselves. This constraint means the decontamination team must resist the common urge to cross to the other side to better decontaminate entry personnel and instead communicate appropriately with entry personnel to accomplish their task.

The science officer is responsible for primary research into the chemical properties of the materials involved, PPE selection, dispersion modelling, zone definition, and decontamination strategy. Typically, there is a science officer and an additional two students to cover the amount of work involved. The science team uses the references stated in Simulation #1, as well as open-source software tools (the Environmental Protection Agency's CAMEO and ALOHA software suites) to help create the response plan and devise a decontamination plan for decon to follow.

Any questions regarding identification, physical, and chemical properties is the responsibility of the science officer and their team.

Finally, the logistics officer and their team of two are responsible for issuing the equipment and PPE used for the response, as well as ensuring it is all returned. The logistics team also helps with other tasks as needed once the equipment issuance is complete.

Students who do not have technical roles are used as assistants for the entry and decon teams, aiding with PPE donning and doffing (usually one assistant per responder). They are responsible for being the responders' "angel", making sure the responder remains safe and performing other tasks as needed. The use of responder assistants gives a second pair of eyes to ensure equipment is donned properly and minimizes responder exertion before entering the hot zone. Overall, this structure allows for approximately 30 students to actively participate in a response scenario with functional jobs with 8 filling in these support roles.

Scenario 3 is run with a reduced team. With much less PPE worn, a simulated decontamination corridor is not staged. As such, logistics and decontamination teams are not utilized, and any students without a role instead observe the activity. The science team and PIO also are not utilized to focus on the communication and bias aspects of the scenario. Students are split into two groups, each with a command team and two entry teams with appropriate support, approximately 12 students. Halfway through pipe assembly, entry teams switch out, and after the first assembly is constructed, a short discussion is held on the challenges teams faced and why they were present. The second group repeats the activity with a new pipe assembly with entry teams switching halfway through its construction.

Equipment

A course of this nature requires a lot of specialized equipment, much of which is not readily available to a typical department. A basic level A ensemble consisting of a fully encapsulated training suit, SCBA, and a pair of response boots costs approximately $5,000. Even if a department could afford the initial outlay for the equipment, there are recurring costs associated with maintenance, such as the regular hydrostatic testing of the SCBA bottle.

As such, training level A suits, boots, SCBAs, person-portable analytical instruments, and other such equipment are borrowed from the authors' non-university institutions. They have been large supporters of the course as it is an opportunity to support the campus community. The current iteration of the course deploys 8 SCBAs, 6 level A training suits, 6 level B suits, approximately one dozen pairs of boots in addition to a variety of gloves and instrumentation and training documentation.

While the scenarios can be simplified to use lower-level PPE, the full experience is of great benefit to the students, requiring the participation of those with access to the necessary equipment. These individuals could be from a local industry or a training group, but a relationship with the organization would have to be established. Alumni support is also an option, as is done in this course. In addition to equipment access, these alumni need to be within a reasonable distance for support, as well as to have the skills necessary to teach the sessions.

The decon equipment used during the response includes at least one garden hose, fittings, brushes, buckets, sponges, sprayers, tarps, and at least two wading pools. Sourcing the equipment locally and storing it on campus makes the course smoother for the alumni instructors.

During the response, the alumni instructors act as overwatch to ensure the scenario is performed in a safe manner. Additionally, they advise the students on many issues that may not have been covered in the lecture session, such as equipment and instrumentation usage, software advice, and PPE problems. They are the simulated resources which provide public safety, medical, and real-world critical information needed for the response. Instructors assume the roles of fire and police chiefs, local leaders, reporters and others, based on their experience responding to actual emergencies.

Observations

The authors are constantly amazed at how well the students handle the practical classes. Routinely, students excel in every role they take on. It is obvious that the opportunity to apply the knowledge they acquire in their fundamental courses and apply it in real time is of benefit to them. There have been students who were uncomfortable in their roles and faced challenges, but that is to be expected. What is important is the opportunity for them to learn something about themselves they did not previously know. Instructors often share their own challenges in similar situations, helping the students build confidence.

The two groups that truly stand out consistently are the entry teams and the public information officer. While the opportunity to don the SCBAs and level A suits is exciting and a big draw for the entrants, the application of the pipefitting skill is the biggest surprise. The students are shown basic skills in pipefitting while the command team works on the response plan. They are given the rules for what they can and cannot do and allowed to develop a plan as to who will do what during their time on air, as well as time to practice the tasks. Throughout the history of the course, all student teams were successful in completing the assigned mitigation tasks. The student entry teams apply their training so efficiently that spare breathing air bottles are no longer needed. While this achievement may seem small, the ability to complete complex tasks while wearing high level PPE is anything but easy. Reduced tactile response coupled with the added stress of wearing a hot, encapsulating suit while breathing supplied air can rattle a seasoned responder, yet every time the course is offered, the teams handle the activities well. The second weekend response, while less stressful, is not easier and requires similar skills which students perform with aplomb.

Dealing with the stresses of wearing the PPE have forced some students to deal with personal traumas in real time. One student in particular was a survivor of a personal attack, making it difficult for the student to don the level A suit. The student was determined, however, to complete the scenario. The instructors and student developed a solution, allowing the student to complete the simulation in a partially unzipped level A suit. The student was able to experience the simulation while simultaneously building their own personal confidence. This is not to say that students have never backed out of the response when confronted with the challenges of PPE. In those cases, students are reassured that knowing their limitations is a big part of their experience and that recognizing limitations prevents placing their team members in a dangerous situation.

The public information officers (PIOs) have been more variable in their success. Few students have ever experienced a real-time interview from a skilled reporter, which requires fast thinking and focus on the key messages that need to be communicated. Some student PIOs quickly figure out the complexities of delivering a unified message while preventing certain information from being released at the wrong time. These students are not rattled and stay on course. On the other hand, an instructor was able to get one student PIO to admit on camera that the company in the simulation was releasing “secret chemicals”. Regardless of performance, students demonstrate a willingness to both learn from what they did and improve in real time.

There have been proven leaders who exhibited a natural ability to direct others towards a common goal. Even more exciting are the students who thought they could not possibly do the tasks assigned to them but rose to the challenge and enjoyed great success. The sense of accomplishment they exhibit makes the effort of conducting the course worthwhile.

Rotating roles among the students between the weekends is important. Originally, students volunteered for the IC role and chose students for the other roles. While this allowed a better understanding of capabilities, the IC’s friends were more likely to get the choice assignments.

Instead, the instructors now select an IC with input from faculty. Students specify their preferences for functional roles, which are used to assign roles for both weekend activities. Students will typically rotate through a command role, a tactical role, and an assistant role, allowing for full exposure throughout both weekends.

Overall, the Hazardous Materials Management course is a benefit to all involved. The students enjoy the practical industrial experience of the alumni instructors and the chance to apply their knowledge and skills to real world scenarios. The alumni instructors are grateful to be involved in furthering the education and promoting the skills of the students about to enter industry and to give back to their university. The department is, in turn, grateful to them for volunteering their time and knowledge and to their institutions for allowing the use of their equipment to make the course possible.

References

[1] OSHA Hazardous Waste Operations and Emergency Response, OSHA Standard 1910.120, 2019.

[2] Kimberly S Stambler and Joseph A Barbera, "Engineering the Incident Command and Multiagency Coordination Systems" Journal of Homeland Security and Emergency Management, vol. 8, no. 1, August 2011, [Online]. Available: https://doi.org/10.2202/1547-7355.1838. [Accessed Nov. 22, 2024]

[3] United States, Department of Homeland Security, National Incident Management System, 2004.