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A Methodology for Training International Space Station Crews to Respond to On-Orbit Emergencies

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ABSTRACT

In spaceflight operations, the training a crewmember receives on responding to onboard emergencies is of utmost importance. In a high-stress, high-adrenaline situation, crewmembers will have to rely heavily on the training they have received to properly execute the correct procedural response. Working within multiple constraints, NASA instructors have developed and continuously fine-tuned the emergency response training in an effort to make it both as efficient and effective as possible.

Critical to this training are the Emergency Scenarios lessons that take place in the Space Station Mockup Training Facility (SSMTF). This training allows the crewmembers to execute the emergency response procedures in a facility that simulates the size and feel of the actual International Space Station. In addition, the classes are typically conducted with the actual crew complement that will be onboard. When possible, real flight controllers, flight directors, and CapComs are included in the training as well.

The authors of this paper have spent several years training crewmembers in emergency response, both as Environmental Control and Life Support Systems (ECLSS) instructors and Station Training Leads (STLs). We have worked with multiple ISS crews and dealt with many different crew complements. This paper will recount some of our experiences from conducting this very important training and attempt to capture some lessons learned that can be used when developing the next generation of emergency training.

INTRODUCTION

Most spaceflight crewmembers agree that emergency training is among the most important training they receive. If an emergency event occurs on-orbit crewmembers want to be able to rely on a thorough and proficient knowledge of emergency operations and procedures. The inherent complexity of ISS and the international nature of the onboard operations have resulted in emergency procedures that are complex by any measure; as a result, a very robust apparatus has been developed to give crewmembers initial training on emergency procedures and ensure proficiency up to (and even after) launch.

One of the most important aspects of complex onboard operations in general, and emergency operations specifically, is learning how to coordinate roles and responsibilities with fellow crewmembers. A primary goal of NASA's emergency training program is to allow the crewmembers who will actually be together on-orbit to practice executing the emergency responses together before they fly.

As with any operation that includes the use of software and hardware, the fidelity of the simulation environment is a critical element to successful training. The NASA training division has spent considerable time and effort to develop a simulator that addresses the most important aspects of emergency response, working within very difficult space and budgetary constraints.

AUTHORS

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Mark Fleming has served as a Station Training Lead (STL) from 2001 to present. The STL coordinates the core systems training an ISS crew receives and as such is responsible for ensuring the crew maintains proper Spaceflight Resource Management (SFRM) through their emergency response training. Mr. Fleming has served as the lead STL for Expeditions 9, 12, and 16. Mr. Balmain has been an STL since 2006, serving as the lead for Expedition 17.

AN OVERVIEW OF ISS CREW EMERGENCY TRAINING

The International Space Station is effectively a Russian space station and an American space station joined end-to-end. The Russian hardware, including emergency response hardware, is based on designs passed down from (or copied directly from) the Mir space station. The US hardware is based on the designs of Space Station Freedom from the 1980s. Besides the obvious hardware design differences, Russian and US spaceflight operations methodologies developed completely independently for 40 years. As a result, the emergency response procedures and hardware on the Russian and US segments vary greatly. The European and Japanese module hardware and emergency response procedures were designed to match the US methodology.

In Russia, crewmembers receive training specifically on Russian segment emergency response hardware and procedures. Likewise, training on US emergency response hardware and procedures takes place in the US. As the international integrator, the US is also responsible for training the crew on vehicle-wide emergency response. This paper specifically discusses the US portion of the crew's training, including both US-segment specific training and vehicle-wide integrated training.

Over a decade of developing crew emergency training, NASA has developed a streamlined and efficient process that addresses the core issues related to crew emergency training within very difficult time constraints. Due to onboard configuration changes, integrating multiple international partners, and complexities of hardware design, the training development process has been evolutionary and not without its share of challenges. Today the standard emergency training flow for a single crewmember in the United States is on the order of 32 hours, including introductory training and proficiency training.

Figure 1 shows the crew's end-to-end US emergency training flow.

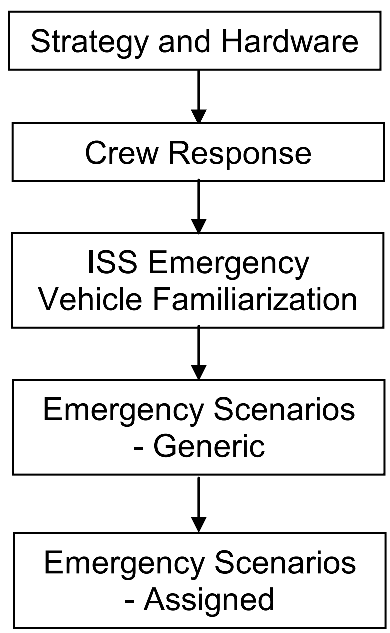

Figure 1 - ISS Crew Emergency Training Flow

Initial Training

When individuals are first hired as astronauts, their knowledge of ISS systems is typically very low. One of their first assignments is to go through what is typically referred to as "AsCan" (or Astronaut Candidate) training. This gives them the basic level of understanding of ISS systems that they need to proceed with their assignments and, if appropriate, further systems training.

Once an astronaut has been assigned to a specific crew they begin receiving their basic core systems training. At this point they receive their Initial Emergency training. Initial training gives the astronaut all of the skills required to properly execute emergency response procedures. The Initial Emergency Training is further subdivided into three groups: Strategy and Hardware, Crew Response, and Emergency Vehicle Familiarization.

Strategy and Hardware Training

This phase of training exposes the student to the overall strategy of emergency response. The emergency procedures are extremely complex, often involving hardware and software response in almost every module of ISS. In addition to the inherent complexities of the procedures themselves, emergency response typically requires interfacing with many of the onboard systems, so an at least basic knowledge of spacecraft systems operations is required. Added to these difficulties are the challenges many crewmembers face of dealing with English as a non-native tongue; this is a challenge that is certainly not unique to emergency training.

There is one Strategy and Hardware lesson dedicated to each type of emergency response: Toxic Atmosphere, Rapid Depressurization, and Fire. These lessons can be thought of as "toolbox" lessons, familiarizing the student with the physical tools that will be available to them in each type of emergency, e.g., the handheld pressure gauge for rapid depressurizations, the fire extinguishers for fires, and the cleanup kits for toxic atmosphere response. There is also a small amount of international integration at this level: while the Russian hardware is mostly trained in Russia, the correlations between Russian and US hardware are shown in these classes.

As important as educating the crewmembers on the three types of emergency procedures is instructing them on the joint operations procedures, i.e., how the procedures are executed differently if a Shuttle is docked. Since the Toxic Atmosphere content is considerably less than Fire or Rapid Depress, the joint operations procedures content is contained in the same class as Toxic Atmosphere.

The total length of the Strategy and Hardware training is four hours.

Crew Response Training

The purpose of the Crew Response lessons is to instruct the students on how to actually run the emergency procedures. As previously mentioned, the emergency procedures are very complex – the current version of the Lab fire location procedure is 26 pages long - and the underlying philosophy behind their execution takes a considerable amount of time to understand. More important even than understanding *how* the procedures are written is understanding *why* they were written that way. Understanding the rationale behind the structure of the procedures helps the crewmembers to more easily navigate the Emergency procedures book itself. These lessons also point out differences in response among elements (e.g., why fire response differs in the Lab from the Service Module) and even within an element (e.g., why fire response differs in the Lab from the Airlock).

One main purpose of the Crew Response lessons is for the students to integrate what they learned in the Strategy and Hardware lessons with the procedures themselves. Previously the crew learned what tools they had to combat an emergency, now they are learning how to use those tools in specific situations.

The crewmembers also begin to learn about the individual roles they might play in responding to an emergency, particularly in a fire. For example, when attempting to isolate a fire, there are three distinct roles that crewmembers will typically play: one will use a Portable Computer System (PCS) to look for indications of an electrical fire, one will use a Compound Specific Analyzer-Combustion Products (CSA-CP) to look for indications of smoke behind panels, and a third will coordinate the procedure response. It is important for crewmembers to understand their specific responsibilities in each of these roles, and the Crew Response Training lessons provide a forum for this discussion. Eventually the crew will need to make specific assignments ("<u>You</u> will operate the PCS, <u>you</u> will operate the CSA-CP, and <u>I</u> will coordinate the procedure response"). This level of coordination typically takes place later in the flow once crew assignments are more solid, but a base familiarization with the specific responsibilities takes place in this series of lessons.

The total Crew Response training takes about five hours of classroom time.

Emergency Vehicle Familiarization
The Space Station Mockup Training Facility (SSMTF) is a one-to-one scale mockup of the entire ISS. It is the most complete ground-based mockup of the Space Station available, allowing the crew to practice end-to-end multielement procedures. One of its primary purposes is to provide a forum for the crew to execute emergency procedures. Any emergency that occurs onboard will have Station-wide impacts. A fire in any module could cause Station-wide smoke contamination. A toxic spill in the Lab could spread through the ventilation system within seconds. A rapid depressurization could be caused by a leak in any module and its location might not be evident without extensive troubleshooting. In the Emergency Vehicle Familiarization lesson, the crewmembers take the tools, procedures, and strategies and begin to apply them in lifelike scenarios.

The first part of the lesson involves a walkthrough of the Space Station Mockup Training Facility (SSMTF), located in Building 9 at Johnson Space Center. The instructor's main focus is to give the students a spatial awareness of the Station and where equipment is located. The SSMTF is the only facility in the world that provides a full end-to-end mockup of the Space Station, so it is particularly valuable for allowing crewmembers to understand where equipment is located and how it is stowed. Facility personnel spend a significant amount of time ensuring that equipment in the mockup reflects its real-world configuration.


Figure 2 - Space Station Training Mockup Facility (SSMTF)

Once the walkthrough of the facility is complete the instructor will exercise two or three cases with the crewmembers to give them an opportunity to apply their knowledge within the context of the spatial mockup. This is by no means a timed exercise or one that is meant to be realistic – the students are encouraged to thoroughly discuss the procedures, come up with alternate approaches to dealing with situations, and work slowly through the response. The primary goal of the exercise is to allow the crewmembers to piece together specifics about the response. Some questions that an instructor might ask while leading this exercise are:

- Exactly which fire extinguisher would you use?
- What do you expect your crewmates to be doing at this time?
- Have you maintained a clear path between yourself and the escape vehicle?
- Do you need to don breathing protection in this scenario?
- What sort of information should you be communicating to ground teams at this point?

The Emergency Vehicle Familiarization is always an enlightening lesson for instructors because it is where all of the pieces of the puzzle start to fit together for the crewmembers. They begin to understand emergency response within the context of the entire vehicle, and their own responsibilities relative to those of the other crewmembers. The types of questions and what-if scenarios that students develop are always different and can often be difficult for instructors to address. The goal is for crewmembers leave the lesson with an understanding of how the procedures and equipment fit together to provide an integrated response to emergencies onboard the Station.

Ground Proficiency Training

NASA's crew training is skills-based; instead of teaching crewmembers how to execute every procedure they might conceivably be called upon to perform, lesson developers parse out the individual skills that are required to execute onboard operations and teach them individually. It would be almost impossible to allow a crewmember to effectively execute every single procedure in training, or to train them on each individual Portable Computer System (PCS) display. Instead, they are taught the skills associated with those procedures and displays and then allowed to exercise those skills in training scenarios and, ultimately, on-orbit.

The Emergency Initial Training exposes the students to all of the skills required to properly execute emergency procedures. Once this is complete, the student enters the proficiency phase of training, where they apply those skills in realistic scenarios and work to maintain what they've learned up to the point of launch.

Due to the enormous amount of training that crewmembers receive, initial skills training for emergency operations can be completed far in advance of launch, up to a year or more. Initial skills training is followed by proficiency training, which allows the crewmembers to regularly exercise those skills in an attempt to ensure that they will be able to reliably execute the procedures once they launch. The emergency proficiency training is split into two parts:

- Generic Scenarios Training
- Assigned Scenarios Training

While externally very similar, these two sets of lessons have distinct requirements and objectives. Both sets are important for making sure that crewmembers understand what they should do in an emergency situation, and what the other crewmembers will be doing as well. The objectives of the Emergency Scenarios sessions are:

- Rehearse response to emergencies
- Exercise previously agreed-to crew coordination and responsibilities
- Allow the crewmember to familiarize themselves with how fellow crewmembers respond to high-pressure situations and observe communication styles and response to stress
- Practice maintaining high-level situational awareness while responding to emergencies and make appropriate crew decisions to reflect the urgency of the situation and the physical layout of the Station
- Integrate skills in various Station systems such as communications and tracking (C&T), Electrical Power Systems (EPS), etc.

Emergency Scenarios - Generic

The primary goal of the Emergency Scenarios - Generic set of lessons is to allow crewmembers to practice executing the emergency procedures from beginning to end in the context of the entire vehicle, with flight-like (or mostly flight-like) equipment. The lessons are not *necessarily* performed with the crewmembers they'll be with on-orbit; in fact, at this point in the training flow, the actual on-orbit crew complements may not be well-determined. That being said, every effort is made to have the correct crew complements participate in these lessons. These lessons often take place four to six months before the crew launches.

Emergency Scenarios – Assigned

In the "Assigned" set of Emergency Scenarios lessons, the actual crewmembers who will be together on-orbit execute the emergency procedures in the ground mockup. By this point, the individual student has a good idea of how the procedures work and the proper means of executing them. This particular session allows them to finalize their response relative to other crewmembers and practice their individual roles. It is vital in this lesson to have the actual complement of crewmembers that will be together on-orbit. During a prebrief session, usually several days before the Scenarios session, the crewmembers discuss their specific roles and who will be performing what parts of the procedure. When they come in for the Scenarios session itself, they perform their specific roles and may tweak the assignments as necessary.

Given the current complications in crew rotations, there may be several different iterations for a crew during a single increment. Up to this point in the Station program, there have usually been three crewmembers on the Station at any given time. Two of the three will be swapped out with a Soyuz rotation; this has traditionally marked the beginning of an increment. During the time that those two are onboard (the length of the increment), the third crewmember may swap out several times on a Shuttle rotation. Thus for a given increment there could be multiple crew complements: Crewmembers A and B may be combined with crewmember C, then D, and then E during a single increment, resulting in three different crew combinations that should each be trained individually. Ideally, each of these combinations would be trained in an Assigned Emergency Scenarios session. There may be multiple sessions scheduled to cover each crew complement, or a single session could have cases addressing each crew combination. This challenge will become only more difficult as the Station program steps up to six-crewmember operations.

Onboard Proficiency Training

Once the crew has arrived on-orbit, they will continue to have training sessions. First, over the course of a six-month increment it can be difficult for crewmembers to retain the skills that they learned on the ground, especially since emergency skills are (hopefully!) not used very often on the Station. Second, whenever a new crewmember arrives on a Shuttle, it is important for each member of the crew to review their individual responsibilities in an emergency situation, given that the response team has changed. Onboard training sessions (typically referred to as OBTs) are scheduled both at regular intervals and whenever a new crewmember arrives to cover both of these issues. And finally, crewmembers need updated training whenever a new module is added to the Station, since the procedures (especially rapid pressurization response) will change with the addition of the new module.

OBTs come in several different varieties. There are safety reviews when the crew initially arrives to familiarize them with the actual onboard location of equipment. (Despite the instructors' best efforts, there are inevitably discrepancies between the ground simulator and actual on-orbit configurations). Each time a new crewmember arrives on a Shuttle to join the two Soyuz crewmembers, an OBT is performed to give the crew a chance to re-familiarize themselves with their individual roles and responsibilities in emergency response. There is also an OBT performed whenever a new module is installed on the Station. With the addition of the new module the emergency procedures change and it is important for crewmembers to understand and be able to properly implement these changes. Finally, there are periodic OBTs run by either US or Russian trainers to give proficiency training in fire and rapid depressurization procedures. These sessions are run approximately once every six weeks.

Of course there have been a handful of cases where crewmembers have actually executed the emergency procedures on-orbit, although fortunately these have all been false alarms. Most notably was during Expedition 12 when Commander Bill McArthur, due to a system misconfiguration, received an alarm that there was a leak of ammonia into the cabin. He executed the toxic atmosphere response, donning breathing protection, closing hatches, and evacuating to the Russian segment before being informed that the alarm was false. Despite the obvious logistical difficulties this situation caused it was a refreshing to know that McArthur's emergency training had been effective and that he'd retained what he'd learned.

EXECUTION OF EMERGENCY SCENARIOS TRAINING

Philosophies

Familiarity through practice, repetition, and discussion is the philosophy applied to ISS emergency training. The crew must be familiar with one another, the command leadership, expectations of the ISS program and ground operations, the ISS vehicle, and the emergency procedures. It is recognized that nearly an infinite number of potential complex emergency scenarios could occur on ISS and it is not realistic to attempt to train each potential event. Therefore, potential emergency events are divided into three main categories - fire, rapid depressurization, and toxic spills. Training addresses several variations on each event, with each variation strategically designed to highlight and emphasize different and unique characteristics of the event category.

The fundamentals of emergency response, procedure structure, content, and utilization, and emergency hardware are first taught to the crew in a classroom setting. After completion of the fundamentals training the crew begins their complex practical training which consists of full ISS mock-up emergency response scenarios. The scenarios start with simple cases and grow more complex as training progresses. Initially the scenarios are basic and allow the crew to familiarize themselves with the responsibilities and challenges of each role played in all three of the major emergency responses. Eventually the crew settles into specific roles they will fill in an actual emergency response and begins to fine tune their techniques for performing those specific duties as training progresses. As the crew becomes more familiar and comfortable with the emergency response, complexities are added to the scenarios, such as medical emergencies or additional systems failures, to challenge the crew and stress their decision making.

Instructors expect crews to memorize the initial response associated with each type of emergency. For example, whenever the crew sees an alarm that indicates a possible leak of ammonia into the atmosphere, they are expected to don a breathing mask, annunciate a toxic leak alarm, and egress the US segment, closing the Node 1 aft hatch along the way. This response (called the “initial response”) should be performed without referencing a procedure. All crewmembers should be able to execute specific initial response actions for an emergency without consulting the emergency procedure book.

Scenarios are carefully chosen throughout the training flow to stress different areas and branches of the procedures to give the crew a broad exposure to the full set of emergency response documentation. Debriefs after every scenario allow the crew to discuss every aspect of a response to a given emergency scenario, often going line-by-line through the procedures utilized in the response. By the end of emergency training the crew is intimately familiar with every emergency procedure product available to them and has actively exercised the majority of the procedures at least once in a scenario exercise.

Scenarios training allows the crew to refine and master their response technique. Initially the crew simply struggles to just follow and execute the procedures error-free and in a timely manner. With practice they become more comfortable with the use of the response products, layout of the vehicle, and recognition of visual and audio cues. Ultimately the crew begins to find efficiencies in their responses to the various types of emergencies. These efficiencies come in many areas - communication, roles and responsibilities, personnel locations, response equipment collection and utilization, etc. The techniques preferred and mastered by each crew differ and are dependent on the personality, communication style, strengths and weaknesses of that particular crew. Scenarios training allows each crew to discover, refine, and master their preferred response techniques.

Familiarization with the vehicle interior layout and locations of all emergency related equipment is another important aspect of the ISS emergency training approach. Vehicle layout and equipment locations are initially discussed in a mockup based introductory lesson. Prior to each scenario session the crew is also given a brief refresher of vehicle spatial layout and available equipment locations. Practice in the scenarios further ingrains the locations of fireports, oxygen ports, meters and gauges, fire extinguishers, and breathing masks and oxygen bottles. Additionally, another key component of the emergency training is educating the crew on vehicle specific potential hazards when responding to an emergency; for example, US flight rules indicate that due to electrical shock concerns Russian fire extinguishers should not be used in the US segment. This subtlety in emergency response is not always immediately evident to new crewmembers. Dozens of safety techniques, general response guidelines, and best practices are introduced and emphasized in every simulation scenario until this knowledge becomes second nature and habit.

It is extremely important that all response exercises are performed in an environment that is as flight-like as possible. Situational awareness and orientation are critical to decision making and require sensory cues that are accurate. Accurately simulating the timing associated with emergency procedures requires a full vehicle mockup that is spatially correct. A moderate-to-high fidelity mockup is required to train an awareness of the locations and availability of critical assets such as communications panels, PCS's, fire suppression equipment, breathing masks, oxygen ports, power switches, etc.

Each ISS increment has a unique commander and crew. The commander, being ultimately responsible for the safety of the crew and vehicle, must thoroughly define and communicate their expectations for every member of their crew and for support from the ground. Although the expectations are often similar from commander to commander, there are frequently differences due to personal leadership and management styles. Expectations become clearly established in the scenario sessions as the crew works through simulated emergencies performing assigned roles and thoroughly debriefs the results after the conclusion of each scenario. It becomes particularly challenging to familiarize the crew with the commander's expectations when multiple combinations of crew are present during the same increment (under the same commander), as is the case when expedition crewmembers rotate in and out of the increment on shuttle flights. The shuttle flights also present a challenge because occasionally in a given increment the crew complement can temporarily grow by 6 or 7 people for approximately two weeks at a time. The ISS crew rotating on space shuttles and the shuttle crews themselves must also understand the expectations of the ISS commander during an emergency. Scenarios training sessions and briefings are added to the training template to ensure all possible crew combinations during the increment have been trained to understand the commander's expectations.

Coordination of the crew-to-crew and crew-to-ground communications during an emergency is a major objective of emergency training. Each commander must determine the most effective and beneficial methods for relaying commands and information between crewmembers and between the vehicle and the ground. The commander must also determine to what extent they would utilize the ground as a resource in an emergency and how often they intend to status the ground on the progress of the onboard emergency response. The preferences of each commander and strengths of each individual crew typically influence different strategies regarding communication. The commander and increment flight director must also ensure they are in agreement on how emergencies are managed. In addition to meetings between the commander and lead flight director, the flight director will often attend scenarios training and fine-tune the communication and coordination expectations between flight crew and ground operations.

Familiarity breeds confidence and confidence reduces stress in an otherwise very stressful environment. Decreased stress reduces errors and results in better decision making. The crew is rigorously trained in all aspects of potential onboard emergencies. The crew trains frequently to create and maintain a sense of familiarity. Their extensive training also allows them to customize and shape the methods and techniques best suited for that crew complement and their familiarity is further reinforced through ownership.

Facilities

Over the years, NASA has spent a considerable amount of time, effort and resources to develop the Space Station Mockup Training Facility (SSMTF) into the ideal facility for training crew emergency response. Crewmembers receive emergency training at facilities in other locations as well (Russia, Europe, and Japan), but the SSMTF in Building 9 at Johnson Space Center is the only end-to-end mockup of the entire Space Station, including one-to-one ratio mockups of each of the habitable volumes.

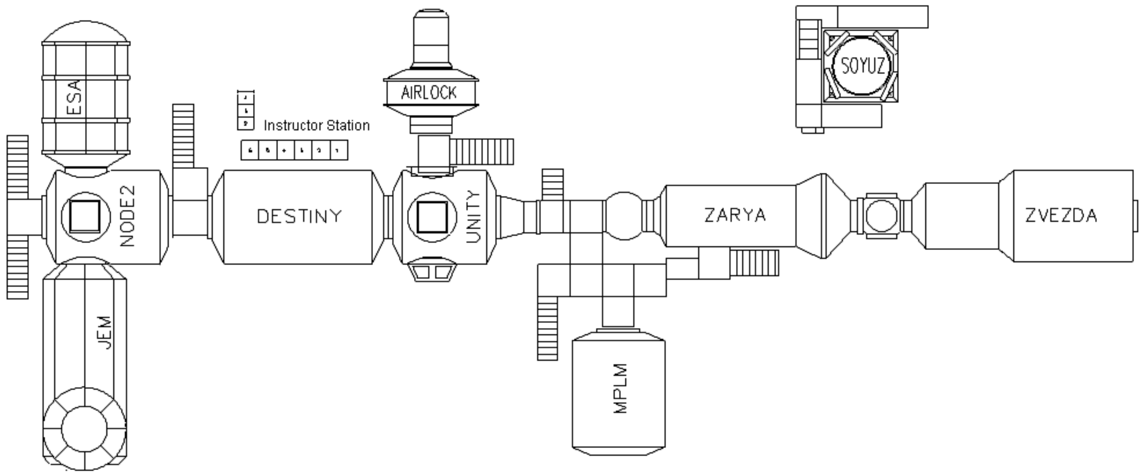

Figure 3 - Layout of modules in the Space Station Mockup Training Facility

In addition to the physical mockup of the Space Station itself, NASA has developed training versions of the essential emergency response hardware. Lightweight versions of the Portable Fire Extinguisher (PFE) and free-breathe versions of the Portable Breathing Apparatus (PBA) are stowed in lockers in the actual locations they are stowed on-orbit. Caution and Warning Panels are mounted in the appropriate locations and will annunciate the proper alarm tones when appropriate. Other pieces of emergency hardware are mocked up and provided to crewmembers as well.

A software simulator connects to the Portable Computer Systems (PCS) laptops in the mockup and allows the crewmembers to execute software steps of the emergency response and see those steps take effect in the software simulation. A high-fidelity communications system has been installed in each module to let the crew communicate with one another across the station and to communicate with instructors acting as ground operators. Lights in the mockups will turn off in response to vehicle powerdowns associate with fire response.

Since instructors are often spread out over a large area and are frequently out of voice range, each one carries a headset that allows them to communicate with one another. This communications system is critical in coordinating proper cues for the students throughout complex cases. There are also approximately ten closed-circuit cameras that allow individuals at the Instructor Station (see Figure 3) to observe the training without taking up space or distracting the students in the mockups.

NASA has also developed some very specialized training hardware that has become particularly useful for crew training. Two examples are the smoke machine and a remotely-operated vacuum gauge.

One of the primary challenges in executing a fire response procedure in a sealed environment is dealing with smoke. Historically during training instructors would simply tell the crew how much smoke was in the cabin and leave it up to the crewmembers to imagine how the smoke might affect their response. Instructors even tried asking the crew to don fogged glasses in an attempt to simulate smoke in the cabin. Eventually NASA acquired a fog generator, the type used during concerts and stage shows to generate clouds of fog. Once the unit had been cleared by NASA human and facility safety personnel, it was integrated into emergency training. It was modified with extensive ductwork to allow instructors to introduce fog into several different modules.

Crewmembers have repeatedly stated that this unit contributes significantly to the fidelity of training. In addition to the visual impairment it provides, it can also help crewmembers identify the source of a fire and thus more readily extinguish it. It also greatly increases the stress associated with extinguishing a fire: one author recalls seeing a student's hands visibly shaking while responding to a fire in a smoke-filled module.

During rapid depressurization response, one of the key skills that a crewmember must learn is determining how much time they have to respond to the leak as a function of the current cabin pressure and the rate of loss of cabin pressure. The execution of this skill is rather complicated: it requires watching a handheld gauge, performing some basic arithmetic to determine a pressure drop rate and then referencing that value and the current pressure against a nomograph to determine a reserve time, which is the amount of time the crew has to find and isolate the source of the leak before they should abandon the station. While not necessarily a difficult skill to understand or execute, there are several steps involved and mistakes can easily be made, particularly in the high-stress environment of a fast cabin leak. During the early years of emergency scenarios training, the training version of the vacuum gauge had a simple dial that was set using a screwdriver; there was no way for the gauge to dynamically move, and thus instructors had to verbally tell the crewmembers the pressure drop rate, which the crewmembers then used to determine a reserve time. Eventually, NASA built a motor-driven, remote-controlled vacuum gauge. Using a laptop outside the mockups, instructors can set a specific leak rate on the vacuum gauge and stop, start, and modify the rate as hatches are closed and re-opened to isolate the leak. As a result, crewmembers can work the reserve time exercise from beginning to end with no instructor interaction. This tool has significantly increased the fidelity of the training environment.

Personnel

One of the advantages of ISS crew emergency training is that it integrates several different systems into a single training scenario. The following personnel typically take part in emergency training, dependent on the type of emergency being trained:

- Station Training Lead (STL): The STL is in charge of integrating the crew's emergency training: they observe each training session, work with Russian emergency instructors to ensure consistency in the crew's session, and coordinate all of the personnel in attendance at the Emergency Scenarios sessions. In addition, the STL helps to evaluate the crew's Spaceflight Resource Management (SFRM), or overall situational awareness, during emergency procedure execution.
- Environmental Control and Life Support Systems (ECLSS) instructor: The ECLSS instructional group is tasked with providing the technical training associated with responding to an emergency. They create and deliver all of the introductory content up to and including the *Emergency Vehicle Familiarization* lesson. During the Scenarios lesson, the ECLSS instructor makes sure the crew is properly executing the procedures and will typically lead the crew through the individual cases. The ECLSS instructor is also in charge of the crew prebriefs and debriefs.
- Systems instructor: The Systems instructor will be present at the Scenarios lessons to give training related specifically to the Electrical Power Systems (EPS). Particularly during fires, the emergency procedures instructor the crew to look for anomalies in the electrical system as indications of a possible source of the fire. The Systems instructor can also provide some insight relative to the Thermal Control System (TCS) when ammonia leak cases are performed.
- C&T (Communications and Tracking) instructor: During emergency cases, the status of communication with the ground team can play a large part in how the crew executes the response. Understanding their communications configuration and how it might change throughout the execution of emergency procedures is critical; the C&T instructor can provide technical instruction to make sure the crew understands how they can communicate with ground teams and with each other on the Station.
- CDH (Command and Data Handling) instructor: The crew is carefully trained on how to respond to different types of onboard alarms. The CDH instructor helps the crew to

understand how the vehicle may generate different types of alarms and what the proper response is to these alarms.

- Med Ops (Medical Operations) instructors: The Med Ops instructors train the crew on some of the hazardous effects of emergencies: the presence of carbon monoxide in a fire, how the human body might respond to low pressures in a rapid depressurization, and why responding quickly to an onboard ammonia leak is so important. In addition, the Med Ops instructor handles most of the training related to smaller chemical spills, such as battery leaks.
- Flight Controllers and Flight Directors: Over the course of the training, the assigned lead increment ECLSS flight controller, CapCom (the individual responsible for communicating between the flight control team and the crew) and flight director (the individual responsible for overall mission success and safety) will often attend the emergency training sessions. Each crew is slightly different in how they respond to emergencies, and it is often useful for the increment ground team to understand the particulars of how "their" crew will respond in a difficult situation.
- Safety office representatives: Members of the NASA Safety Office attend the crew emergency training to look for efficiencies in crew response, ground team actions, and vehicle design.
- Russian instructors: When possible, the Russian instructors who provide ground emergency training at Star City are invited to support emergency training in the US. This cross-pollination allows instructors on both sides to provide more coherent training to the crews. Likewise, US instructors and Station Training Leads are often invited to support emergency training in Russia.

CHALLENGES OF EXECUTING EMERGENCY SCENARIOS TRAINING

Facility constraints

As previously mentioned it is important to maintain a flight-like environment for crew training, but there are of course budgetary and physical limitations on this fidelity. As much as we would like to have a perfect replicate of the actual Space Station configuration, cost and the requirements of working in Earth's gravity prohibit this.

An example of these limitations is training the crewmembers how to operate a US hatch. When the mockups were originally built, full-scale metal replicas of the hatches were built and installed. Once crews began training, the hatches were found to be far too heavy for real-time training use; each hatch required two persons to lift and a non-flightlike mechanism for keeping it open. As a result, hatch training was completely unrealistic and effectively useless. Elsewhere in the training facility there was a single hatch trainer with a counterbalance to allow it to be opened and closed, but since it was not part of the Space Station mockup it could not be integrated into Emergency Scenarios training. Over time, these overweight hatches were replaced with lightweight hatches built out of a cardboard-like placard material with plastic latching mechanisms. The hatches can be operated by a single individual and allow for much more realistic training, particularly when executing the rapid depressurization response which requires opening and closing hatches to isolate leaks.

Another example of facility limitations is the Portable Breathing Apparatus (PBA) used during fire and toxic atmosphere response. The flight article consists of a full-face mask connected to a high-pressure bottle filled with pure oxygen. For safety reasons, it is obviously unreasonable to ask students to carry a high-pressure bottle with them during emergency training. But without gas flowing into the mask, CO_2 buildup becomes a significant concern. In response to this issue, SSMTF engineers obtained flight-like masks and removed the pressure regulator, thus allowing a free flow of ambient air into the mask. By connecting these masks to unpressurized bottles, a reasonable simulation of the onboard PBA is used during crew training. A high-fidelity mask connected to a bottle of high-pressure air (not pure oxygen) is stored separately and crews are allowed to practice with it under more controlled settings.

Scheduling constraints

One of the most significant challenges to executing emergency training is simply one of schedule. Due to its high fidelity, the SSMTF is in constant demand for training or engineering analyses. As a result of multiple demands on the facility, the building managers have developed a scheduling priority list. The highest-priority demand on the facility is real-time mission support; if there is a problem on ISS, engineers can use the SSMTF to do structural analysis, fit-checks, etc. to understand how to respond to the situation. These sessions are usually very time-critical, thus their first position on the priority list. Second-highest priority goes to prime crew training, including Emergency Scenarios training. This high priority means that scheduling is significantly easier than it *could* be, although not without its share of challenges.

A major difficulty in scheduling Emergency Scenarios sessions is making sure that all the crewmembers are in the country at the same time. Crew schedulers work hard to make sure that training schedules overlap, but with the participation of crewmembers from as many as three different countries, this can be very difficult. Since team coordination is such an important element of emergency training, having all three crewmembers present is critical. As the crew on the Space Station increases to six, overlapping crew schedules will become an even greater issue. Opportunities to train all six crewmembers in a single emergency session may be scarce, and we will need to find even greater efficiencies to make sure the required training objectives are met.

Working with international partners

More than most other complex operations, emergency response by its very nature requires a Station-wide response. A fire in one segment can affect breathing air across the entire stack. Deactivating electrical systems in one module might affect operations in another. And of course a rapid depressurization can take place in any module and the response to the condition must take place vehicle-wide. As a result, instructors must maintain an ongoing dialogue with their International Partner (IP) counterparts. Configuration or procedural changes can affect the operational philosophy in a single module which would in turn change the response vehicle-wide. It can often be very difficult to maintain awareness of these changes, so emergency instructors have spent a considerable amount of time developing open lines of communications with the training counterparts overseas. NASA instructors will often travel to observe training in other countries and open invitations are extended to IP instructors to observe training in the US.

In addition to maintaining flight-like facility configurations, there are often differences among IPs in training methodology. The Russian space program has had fifty years to develop its spaceflight training independently and their techniques are, needless to say, very different from the methods applied in the US, Japan, or Europe. Conversely, Japan’s manned program is very young and the techniques they choose to apply can be difficult to integrate with other training programs. NASA, as the international integration lead for ISS, bears the responsibility for making sure that the overall training for the crew is as effective and efficient as possible. Several forums exist within NASA’s training program in general, and within the emergency training program specifically, to facilitate the integration of all four international partners.

Finally, there are always difficulties related to language differences. Integration takes place among IPs in English; most international partner instructors speak English and if they don’t interpreters are used. Nevertheless, language often presents a significant barrier when presenting highly technical training. Emergency instruction often accounts for language difficulty and accents: all procedures are written in both English and Russian, students are asked to speak slowly and clearly, and when necessary phonetics should be used. For example, it can be very difficult to hear the difference between a call for the “LAB1P6” rack and the “LAB1D6” rack, so students are instructed to say “LAB-1-Papa-6” and “LAB-1-Delta-6.” Repeated exposure to the procedures can often help students develop the necessary linguistic tools to overcome language difficulties.

SUMMARY AND CONCLUSIONS

As NASA begins to move into the next generation of manned spaceflight with the development of the Crew Exploration Vehicle (CEV), it is important to take into consideration the lessons learned from the past ten years of development of ISS crew emergency training. While certainly not a comprehensive list, the following items may be valuable as training facilities, procedures, and processes are developed.

- Consider the important crew interfaces when building training facilities. When building a training mockup, designers should give careful consideration to the fidelity of the hardware with which the crew will actually interface. As stated previously, the hatches in the SSMTF were not originally designed to be manipulated by students. As it became evident that hatch manipulation was a critical skill in the proper execution of emergency training, the hatches had to be re-designed and retrofitted to accommodate this need. It would have been much more cost- and time-effective to have initially built the training facility with this need in mind.
- Design a training plan with inherent flexibility. In a perfect world, instructors can define the ideal number of hours for students and training can be scheduled accordingly. As we have discussed, crewmembers have many other constraints on their time besides training, and time is a precious commodity. Instructors should build training flows that can be easily manipulated to meet these needs. For example, a training session that can be delivered in either two two-hour blocks or a single four-hour block would give crew schedulers more leeway.
- Only use high-fidelity mockups when necessary. It is usually an instructor’s first instinct to use a high-fidelity mockup as often as possible. As discussed above, there can often be other demands on these facilities and over-constraining a crew’s schedule to require them can place unnecessary strain on an already strained system. Instructors should consider these high-cost facilities as a limited resource and design their training to use other lower-demand facilities when possible.
- Consider how technology can (and shouldn’t) be used for training. The remote-controlled vacuum gauge discussed previously has been extremely beneficial for crew training. While technically complex, the benefits of having a “live” vacuum gauge during the execution of emergency procedures are enormous. Instructional designers should consider how technology can be used creatively to enhance training. Conversely, using technology for technology’s sake only serves to increase the cost and complexity of delivering training.
- When training with international partners, integrate them into the process as early as possible. It is far more difficult to include another partner in the training process once flows and lessons have been developed. If future programs call for participation from other organizations (international or otherwise), their input should be called for early during the training development process.

Emergency training, regardless of space program it is created for, will remain among the most critical and important that any crew receives. It can also be among the most complex training that instructors will develop and deliver, requiring extensive integration both inside and outside NASA organizations. However, by understanding the history of emergency lesson development, future instructors can continue to make the training an important part of keeping astronauts safe as they explore beyond Earth’s grasp.