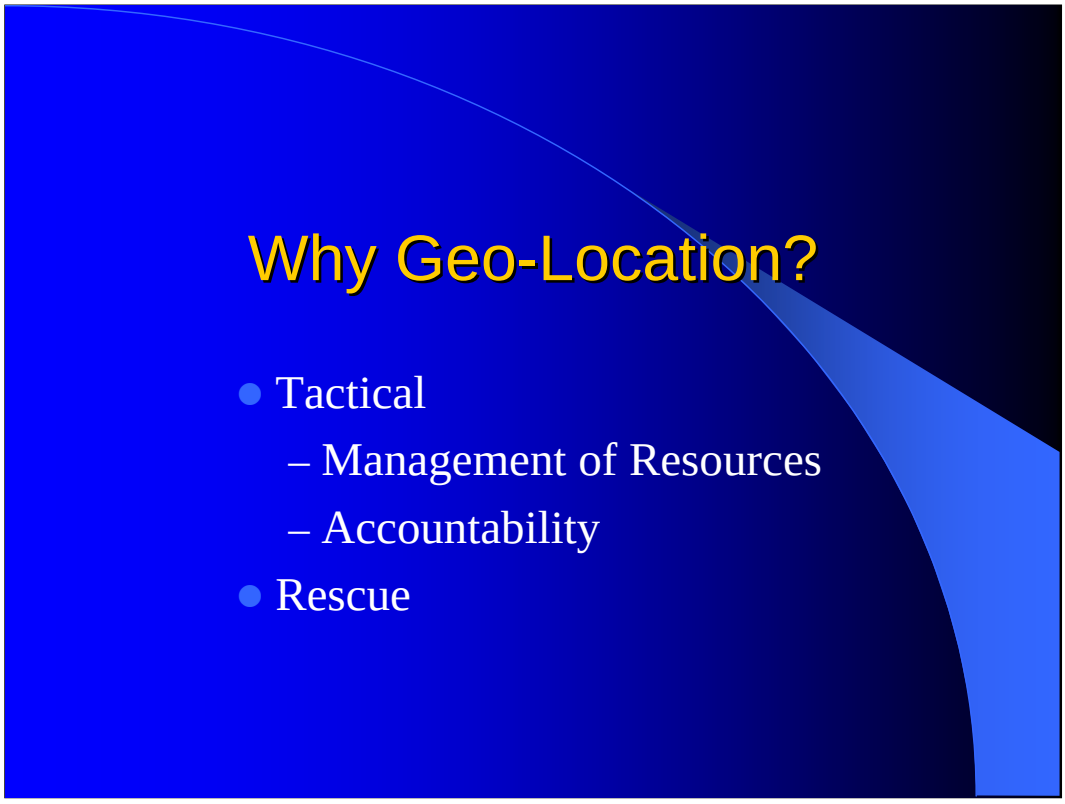
This presentation will focus different technologies that are being used or could be used in a system to locate and rescue firefighters, particularly in buildings and other structures.

NOTE: the symbol “»” is used to indicate a mouse click or right arrow key.



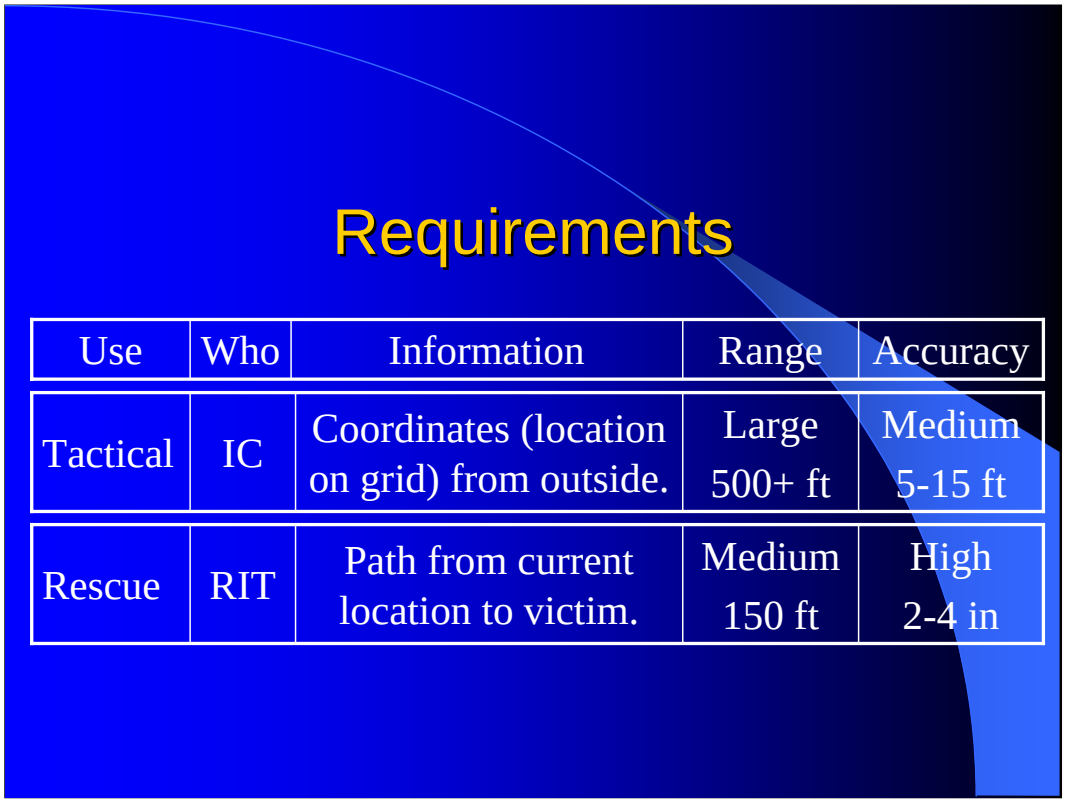
Why are we interested in geo-location? There are essentially two different situations in which you want to know the location of firefighters.

» The first could be classified as tactical, and involves two issues:

» Management of resources at the fire scene,

» and accountability. In both of these issues, the incident commander needs to know roughly where the firefighters are to be sure they are in the best position to carry out their duties and to keep an eye on them in case anything goes wrong.

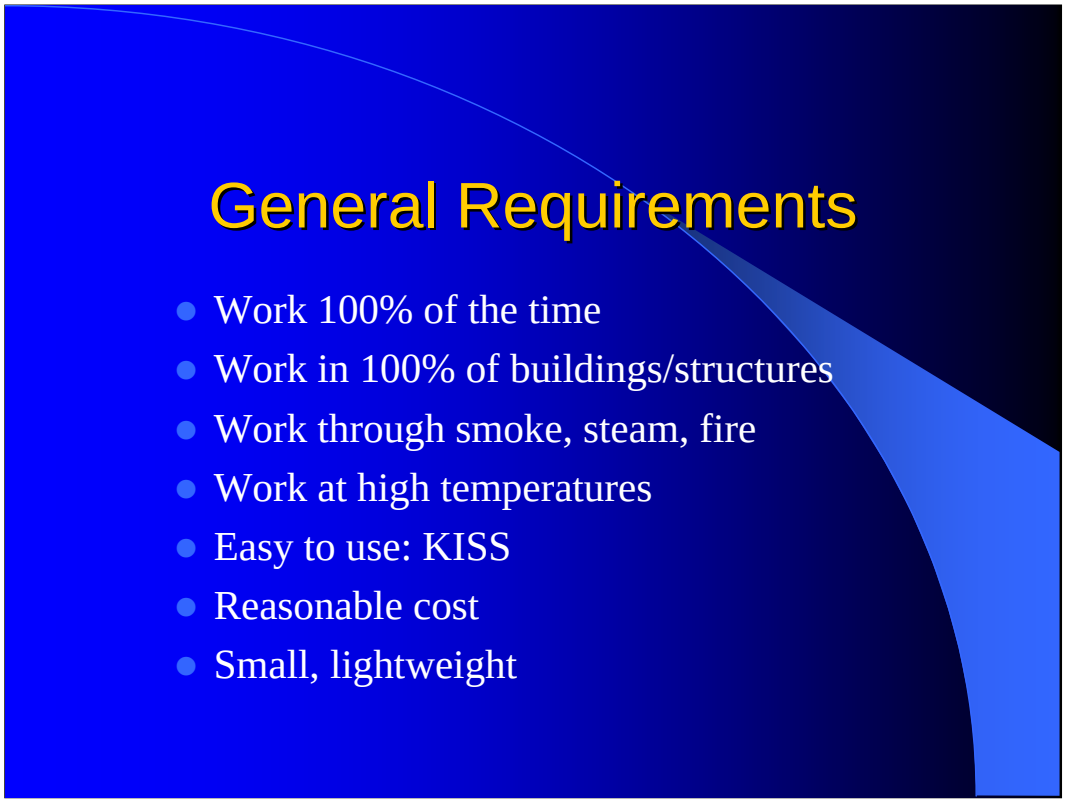
» The second situation in which you want to know where the firefighters are is if a Mayday is called and a rescue is required. In this case, you want to know EXACTLY where they are so you can get to him. In this case, you are more interested in the path that leads you to the victim.



The two situations, Tactical and Rescue, have somewhat different requirements, including who needs what information, the range over which the system must operate, and the accuracy.

» For the Tactical situation, the Incident Commander would want to know the firefighter's coordinates; that is, his location on a grid. The system would need to work over a large range, probably in the 500 to 1000 foot range. For wildfire situations, the range could be even larger, depending on the extent of the fire and the number of command centers. The system would need to be only moderately accurate, say on the order of 5 to 15 feet.

» On the other hand, for the Rescue situation, the RIT team would need to know the actual path from their current location to the victim. The system would need to work over a smaller range, on the order of 150 feet, but would need to be much more accurate – on the order of 4 to 6 inches. The reason for the higher accuracy is because the RIT team would need to know on which side of a wall the victim was located; the path to the victim would depend heavily on which room he is located.



There are other general requirements for a system to be useful to the Fire Service:

» The system needs to work 100% of the time.

» It should work in all buildings and structures, not just in most of them.

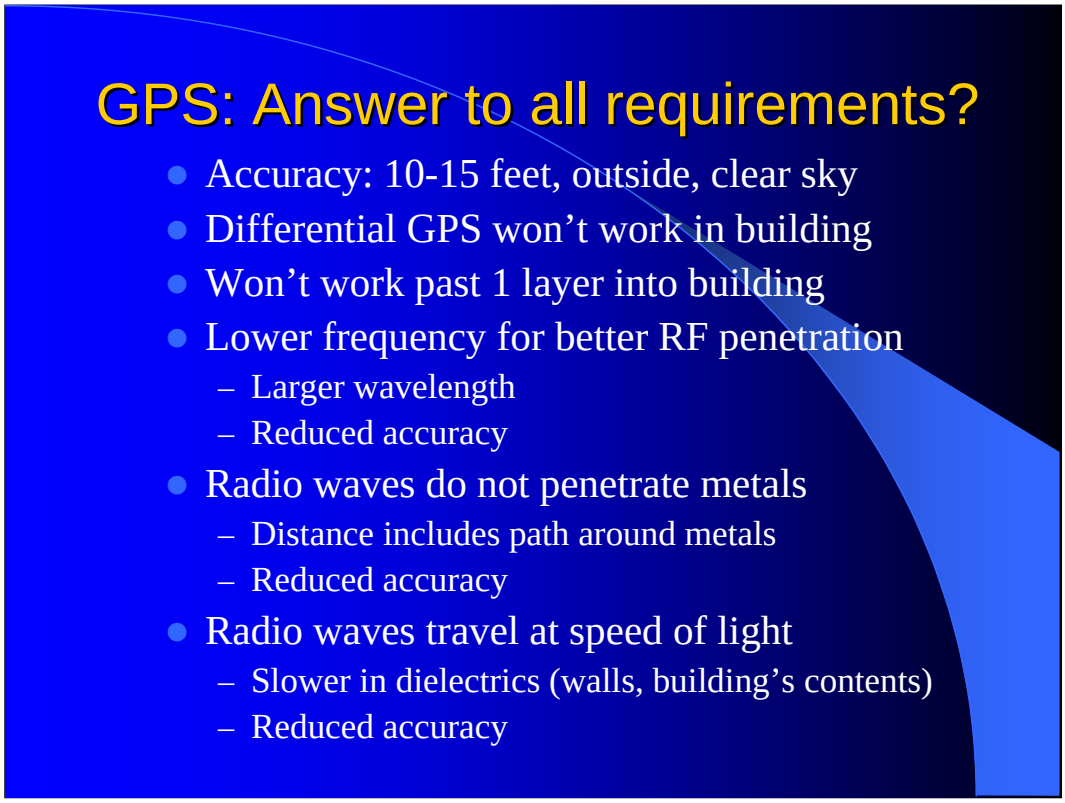
» It must operate with all the environmental problems of the fire scene, including smoke, steam and fire.

» It must operate at high temperatures.

» It must be easy to use; “Keep it simple” definitely applies.

» Ideally the system will not be cost prohibitive.

» Any parts of the system that will be carried by the firefighter must be small and lightweight.



The big question is: Can GPS meet all of the requirements? GPS, the Global Positioning System, has been fully operational since 1993, and would seem to be the perfect solution to all of the requirements. Let's take a look at how well it performs.

» In a clear sky situation, outside a building, the accuracy is typically about 10 to 15 feet. Right away, it appears that GPS would not be good enough for Rescue, but would probably be fine for Tactical situations.

» Differential GPS, which improves accuracy substantially, only works when the radio path is identical for two receivers and will not work in buildings.

» Furthermore, GPS, as presently configured, does not work inside buildings. In fact, it often won't even work 1 foot into a building. So what could be done? The problem is that the high frequency radio waves used by the GPS satellites, 1.5 GHz, does not penetrate the lossy dielectrics used as the building materials. You're probably familiar with the fact that cell phones in the 600 and 800 MHz frequency range may not work inside buildings. Even getting good reception of FM radio stations, which are in the 100 MHz range, may be difficult. However, most buildings can provide reasonable reception of AM radio stations, which are in the 1 MHz range.

» Thus a system could be designed using the basic principles of GPS but using a lower frequency so that the radio wave would penetrate the building better.

» However, using a lower frequency means that the radio wave has a longer wavelength.

» This, in turn, means that the accuracy of the system will be reduced. If you reduce the frequency to the FM band, the frequency is reduced by a factor of 15. This would mean that the accuracy would be reduced by 15, resulting in an accuracy on the order of 150 to 200 feet. Obviously this would be completely unacceptable for use inside buildings.

» Another problem: radio waves do not penetrate metals.

» Any distance measurement includes the extra path length around the metal,

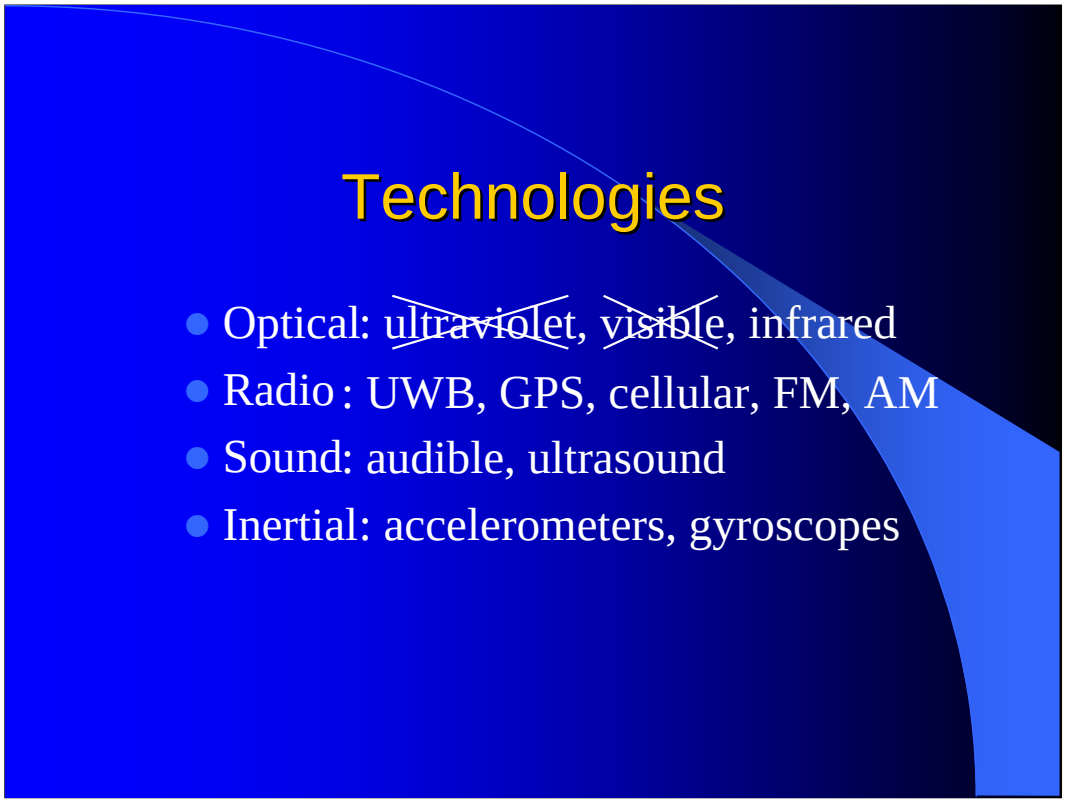
» resulting in reduced accuracy.

» Furthermore, since radio waves travel at the speed of light, any distance measurement depends on the properties of the material that the wave passes through.

» Since the speed of light is slower in dielectric materials (which includes walls and contents of the building),

» the result will be additional reduction in accuracy.

Remembering the accuracy requirements, it seems clear that GPS techniques will not work at all for Rescue situations. On the other hand, since the accuracy requirements for Tactical situations is much less than for Rescue, it may be possible to design a GPS-like system purely for Tactical situations.



So, if GPS can't meet all the requirements, particularly for Rescue situations, what technologies could be used?

» The most promising technologies are optical waves, radio waves, sound waves, and inertial guidance techniques.

» Since the first three are waves, they automatically provide a mechanism for information to pass from the firefighter to the rescuer or incident commander. On the other hand, inertial techniques simply keep track locally of a position, so radio or some other method would need to be combined with the inertial sensors to make a complete system.

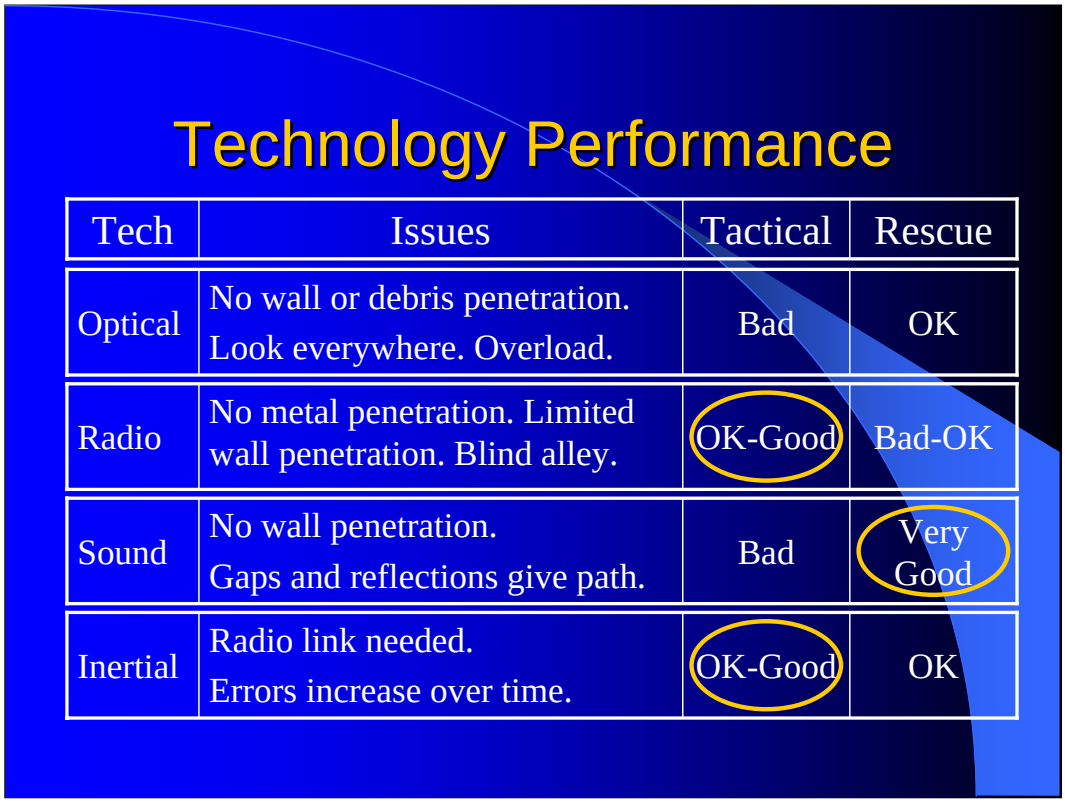
» Optical technology includes ultraviolet, visible, and infrared portions of the spectrum.

» We can immediately rule out the ultraviolet and visible portions because they are scattered by smoke. The only portion of the optical spectrum available is that in which the Thermal Imaging Cameras operate, or the long-wavelength infrared region at 8-14 microns.

» Radio covers the complete RF spectrum, from Ultra-Wide-Band down to the AM radio band and even lower. We must remember that for radio waves, the limitations discussed about GPS apply equally to all other uses of radio waves. That is, radio waves slow down in dielectrics and do not penetrate metals.

» Sound includes both audible sound (which is between about 20 Hz to 20 KHz), as well as ultrasound (which has a frequency above the normal hearing range). Audible sound obviously applies to PASS devices.

» Inertial guidance systems use either accelerometers or gyroscopes to keep track of the movement of the firefighter.



How well do the four technologies perform? That is, excluding such issues as cost and weight, how accurate would a system be using the particular technology in all possible buildings and in all situations?

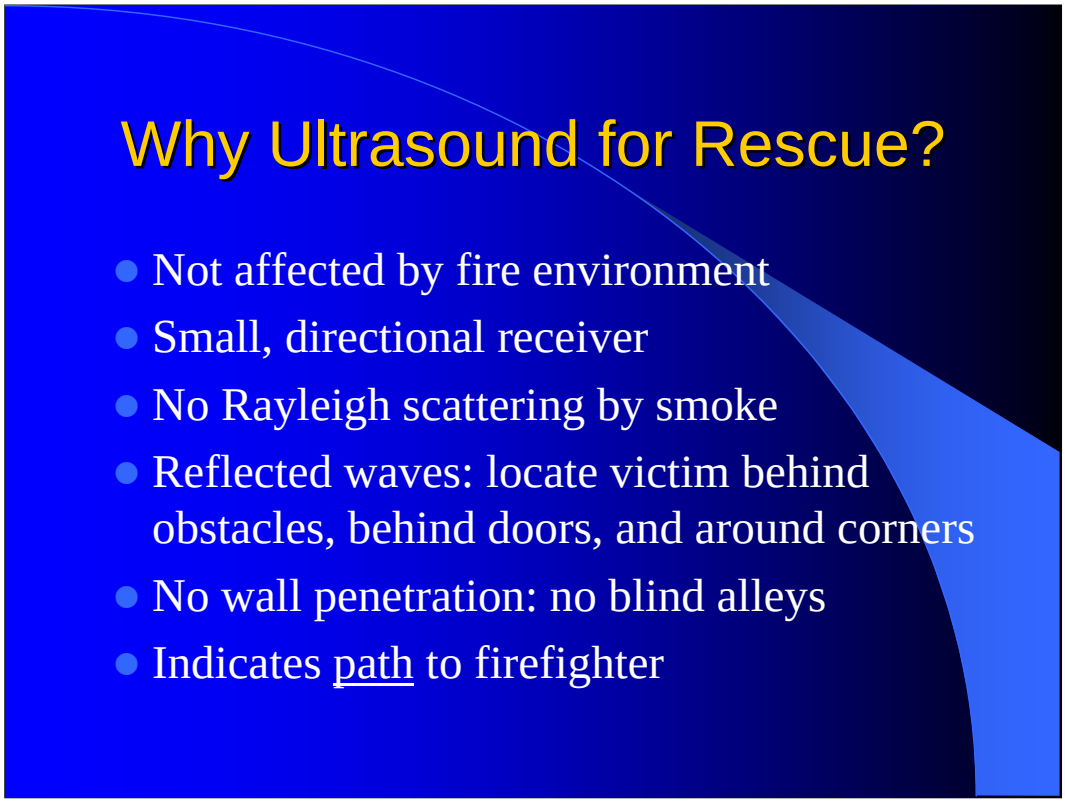
» For optical systems (and we are restricted to the thermal portion of the spectrum), there are several primary issues that determine system performance. First, optical waves do not penetrate walls, so performance is Bad for Tactical situations. That is, it would be very difficult to determine the firefighter's location from outside the building. For Rescue, use of optical systems require that the searcher look everywhere. In addition, optical waves do not penetrate debris. Furthermore, thermal sensors can be overloaded by steam and other heat sources. Thus optical technology would be rated as OK for firefighter Rescue.

» As we pointed out before, radio waves do not penetrate metals, and have limited wall penetration at high frequencies. Remember that for Rescues, we need to know the path to the victim, which is not provided by a radio-based system. In order to prevent going down blind alleys, we would need to have an accurate map of the building. As a result, a radio-based system would be OK to Good for Tactical situations, but would fare quite badly for Rescue situations.

» Since sound will not penetrate walls, sound-based systems would generally fare poorly for Tactical situations. That is, it would be very difficult to pinpoint a firefighter's location from the outside of a building using sound. However, unlike radio waves, sound waves are reflected by virtually all surfaces. As a result, sound-based systems would be Very Good for Rescue situations, because the reflections of the sound waves allow the RIT team to follow the sound path back to the victim. We will look at a sound-based system shortly.

» The last technology, Inertial Guidance, requires the information of the firefighter's location to be transmitted to the outside of the building or to the RIT team. Thus a complete system would require a radio link. Since inertial errors increase over time, the performance would be OK to Good for Tactical situations. For Rescue situations, the system would tell the approximate location of the firefighter, and could provide information about the path that the firefighter took to get to the present location, but would provide no information about more-direct paths from the RIT team to the firefighter. As a result, the technology would be OK for Rescue situations.

If we look at the whole chart, the best technology for Tactical situations would be either radio or inertial guidance. For Rescue situations, the best technology would be sound, or ultrasound.



Our company has developed a system that we call Pulse, that uses ultrasound to rescue firefighters. Why did we choose ultrasound for this system?

» First, the ultrasonic signal is virtually unaffected by the fire environment.

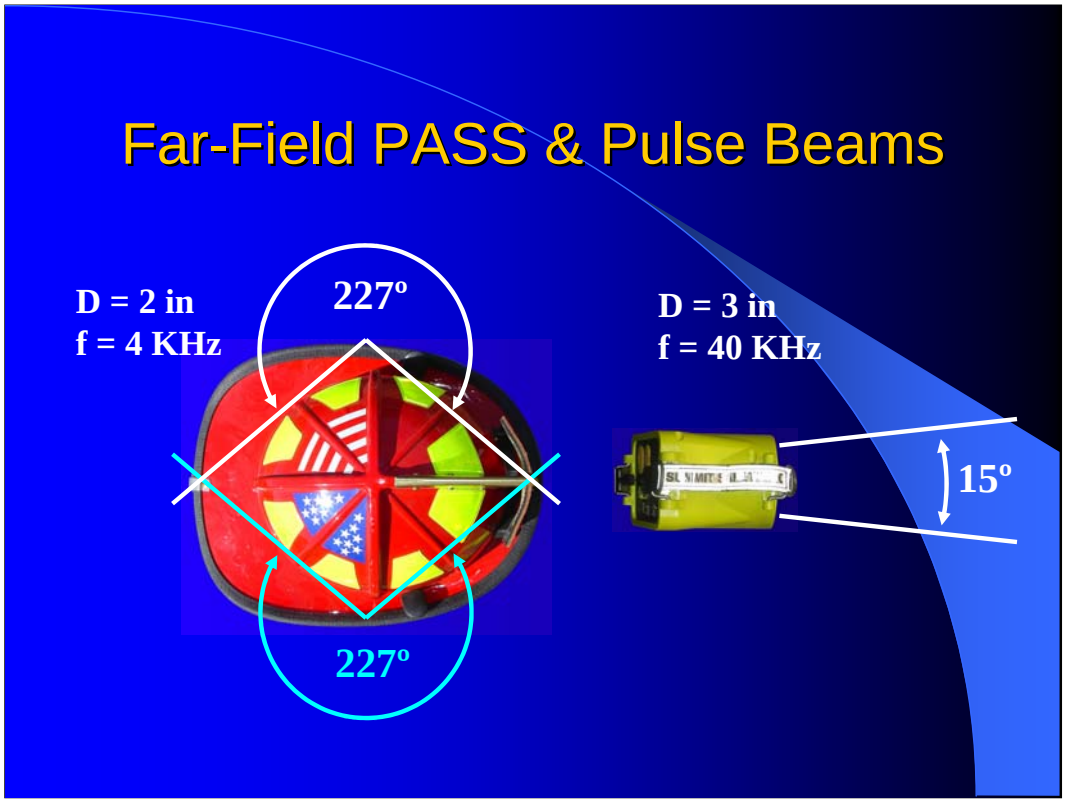
» Second, because the wavelength is small, we can build a small, hand-held, directional receiver.

» Third, smoke has very little effect on the beam.

» Fourth, sound waves are reflected by almost every surface. Sound waves, particularly ultrasonic, can pass through very small openings. As a result, the system is able to locate the disabled firefighter behind obstacles, behind closed doors, around corners, even if the firefighter is covered by debris.

» Since sound waves do not penetrate solid walls, the rescuer is not led down blind alleys.

» If a firefighter is wearing an ultrasonic homing beacon, and its sound is able to get to the rescuer, then the rescuer simply follows that sound back to its source. Note that the sound follows a path, and the rescuer simply follows that path back to the disabled firefighter.

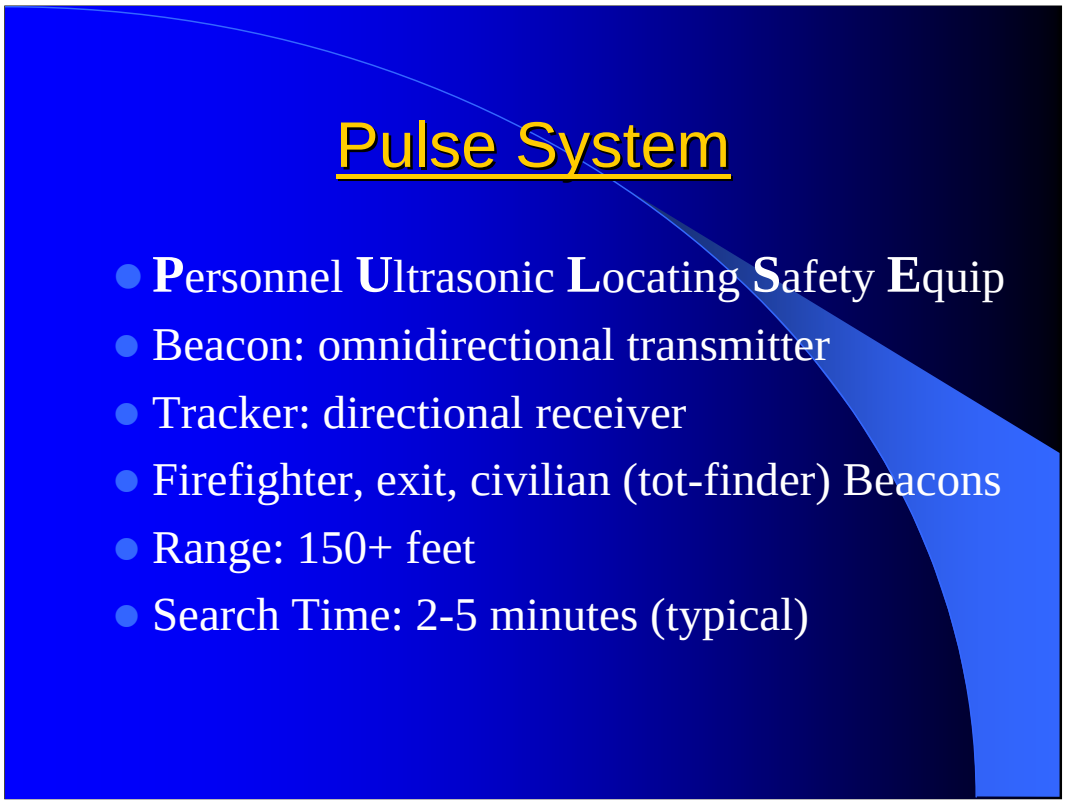


When PASS devices were developed, many people thought they would be ideal for locating a downed firefighter. However, this has not turned out to be the case, and the primary reason is that a person's hearing is not very directional.

» Any type of receiver, transducer, antenna, or lens has what is called a beam pattern. If we consider the receiving beam pattern for a person's ear, and we assume that the size of the ear is 2 inches and we are listening to the highest frequency allowed for a PASS device, which is 4 KHz, then we find that the ear receives signals from an angle of about 227 degrees. In other words, the ear can pick up sounds from almost any direction.

» If we further consider the other ear, then we see that hearing is essentially non-directional. As an example of how difficult it is to locate a PASS device, consider how hard it is to locate a beeping smoke detector with a low battery. Another example: a cell phone rings and everyone in the room reaches for their phone. You may have noticed the large dishes used at the sidelines of a football game to pick up the scrimmage sounds. If our ears were four feet in diameter, they would do a much better job of locating a PASS device.

» On the other hand, if we consider a hand-held device, only 3 inches in diameter, and use an ultrasonic frequency of 40 KHz, then the beam pattern is about 15 degrees. In other words, we can make a small, directional receiver if we use ultrasound.



We call our system Pulse,

» which stands for Personnel Ultrasonic Locating Safety Equipment. It consists of two units.

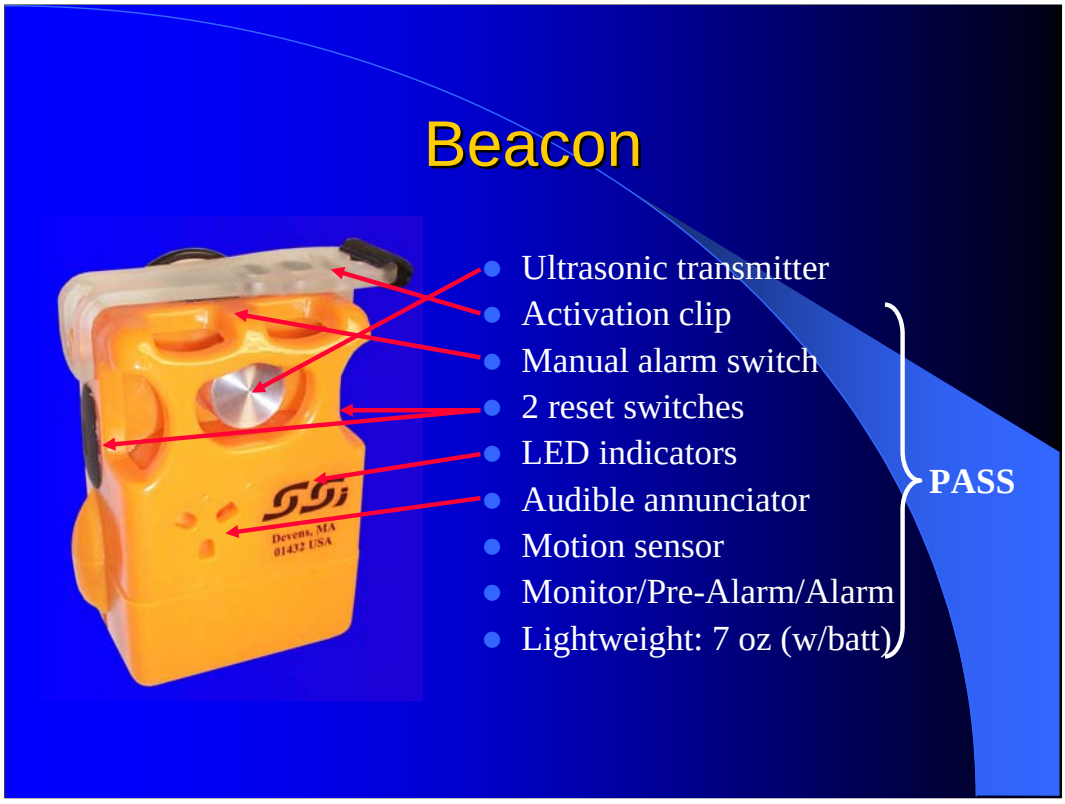
» The first is called the Beacon, which is similar to a PASS device, and includes an omnidirectional ultrasonic transmitter. The Beacon is worn by the firefighter. If the Beacon goes into alarm mode, it transmits an ultrasonic signal in all directions.

» The second unit is called a Tracker, and is simply a directional ultrasonic receiver. The Tracker is used to pinpoint the direction of the Beacon.

» In addition to the firefighter Beacon, we are developing an Exit Beacon, which a firefighter can use to mark the point of egress from a building or room. We are also developing tot-finder Beacons to identify children's bedrooms.

» The Pulse system currently operates at a maximum range of about 150 feet.

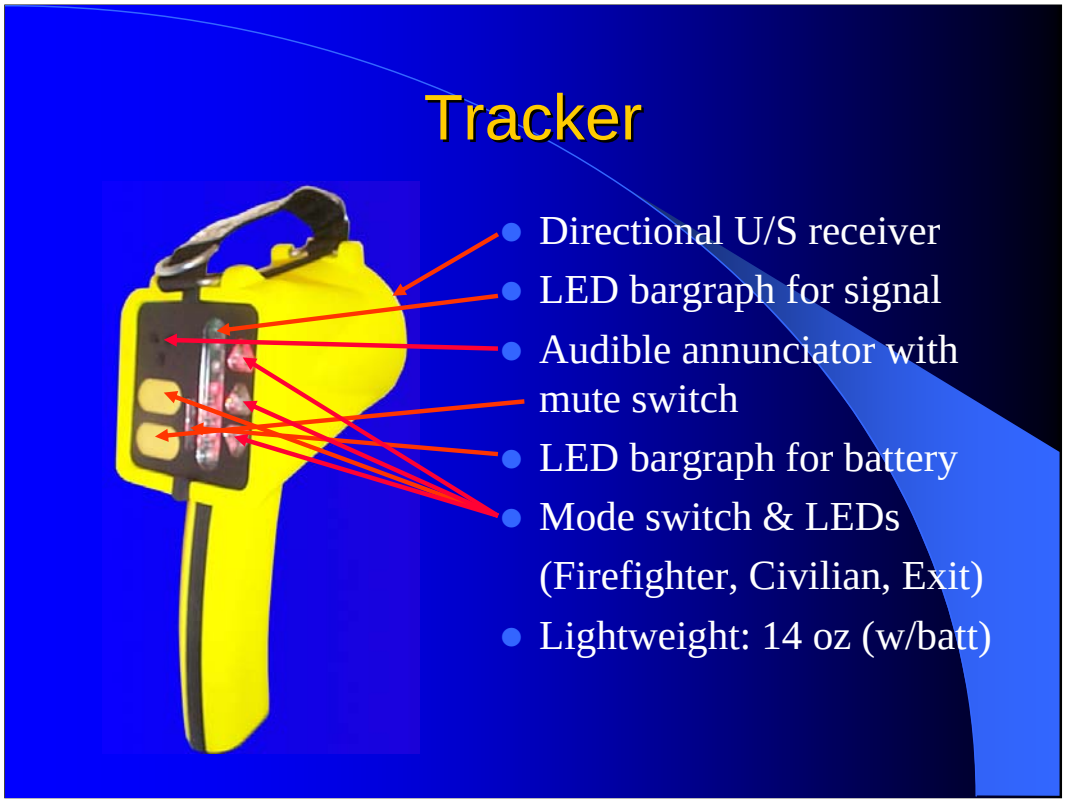
» The Pulse system has been used in a large number of hands-on-training exercises. Our experience is that search times are typically in the 2 to 5 minute range over a wide variety of situations, ranging from wide-area searches to searches in confined spaces.



The Firefighter Beacon is similar to a PASS device

» and houses the omnidirectional ultrasonic transmitter. The unit is made from impact-resistant, high-temperature plastic.

» The Beacon also has standard PASS features as required by NFPA. These include an activation clip to automatically turn the Beacon on; a manual switch to allow the firefighter to turn on the alarm; two reset switches; LED indicators to show that the unit is operating; a loud, audible annunciator; and a motion sensor. Like PASS devices, the Beacon operates in Monitor, Pre-alarm and Alarm modes. The unit is lightweight, weighing only 7 ounces. Half of the weight is due to the 9-volt battery.



The Tracker, which is used by the rescue team, contains

» the directional receiver, which picks up the ultrasonic signal from the Beacon.

» The strength of the signal is displayed on a bar graph. The lights are extremely bright, and can be seen through very heavy smoke. The rescuer scans a room, much like using a flashlight, and searches for the strongest signal. Then by following that signal, the Tracker leads the rescuer to the disabled firefighter.

» The Tracker also has a mode switch, which allows the rescuer to select the firefighter, tot-finder, or exit Beacons.

» A second, smaller bar graph displays the condition of the unit's batteries.

» In addition to the bar graph, the Tracker has an audible annunciator, which beeps at a faster rate when the Beacon signal is stronger. The beeper can be muted by pushing a switch.

» The Tracker weighs less than one pound, with half the weight due to the four AA batteries in the handle.

This example occurred at the Firehouse Expo in San Diego in February, 2003. The victim, a 200-pound dummy, was placed just inside the open doorway of an office at the rear of a small office complex. The search teams consisted of three firefighters with full turnout gear and Nomex hoods reversed to block visibility.

» The main rope was secured at the banister in the stairwell. The team leader entered the building and found a hallway leading to the left. He sent firefighter #2 to the right, secured to the main rope with a tag line, and continued down the hall with the firefighter #3 (green) until he reached a counter.

» Firefighter #2 did a right-hand search and found a door to a small office. He opened the door and searched the office, finding a second (closed) door. Since he was near the end of his rope, he returned to the leader and announced that the only thing he found was a door.

» The team leader instructed firefighter #3 to do a left-hand search. Firefighter #3 searched the room, finding a couch, and then found the wall of the office. He proceeded along the wall, reaching out into the room with a Haligan tool,

» and missed the doorway where the victim was located.

» As he passed the doorway, he actually kicked the feet of the dummy without realizing it was the victim. He continued to search a small cubicle and eventually returned to the team leader and announced that he had found nothing.

The three firefighters then followed the hallway back to the office and located the closed door found by firefighter #2. They opened the door and the team leader went forward and immediately found the wall of a cubicle. He then instructed firefighter #2 to search to do right-hand search.

» Firefighter #2 went around the corner and searched a small cubicle and then reached the hallway to the right and, being near the end of his rope, left the rope bag and returned along the rope to the team leader.

» Firefighter #3, searching to the left, again covered the same room he had searched earlier. By the time he found the couch, he began to realize that he might be covering the previously searched area.

» He again missed the doorway, and kicked the dummy for a second time as he passed the doorway.

» He repeated the search of the cubicle and then returned to the team leader.

The instructors informed the group that the hallway to the right was off limits, so the group went straight ahead and this time found the doorway and the victim.

» The total time, just to find the dummy, was about 35 minutes.

In this evolution, a Pulse Beacon was placed on a chair behind the desk in the same small office as the previous blind search. The Beacon was placed into muted alarm mode (that is, ultrasound on, but audible sound off).

» One firefighter, with his Nomex hood reversed to block his vision, used the Tracker. He entered the building and as he found the hallway to his left, he picked up a signal from the Beacon.

» He followed the hallway and the signal became stronger. He reached the counter and scanned to his left, finding a much-reduced signal level. He then went around the counter by going to his left and headed straight towards the office doorway. He continued into the office and ran into the desk. He went around the desk and went straight to the Beacon in the chair.

» The total time to reach the Beacon was between 4 and 5 minutes using the Pulse system.

Because the previous search using the Pulse System was essentially a direct line to the victim, one instructor decided to give the system a more-difficult test. He said he would hide the Beacon and see if the second instructor could find it. The Beacon was put into muted alarm mode (ultrasound on, audible sound off).

The instructor went down the hall that was off limits for all the previous searches, and passing a first bathroom, he went into a second bathroom at the end of the hall. He went to the far corner of the bathroom and placed the Beacon on the floor and covered it with a metal waste basket. As he left the bathroom, he closed the door. After going back down the hall, he handed the Tracker to the other instructor and told him, “See if you can find it.”

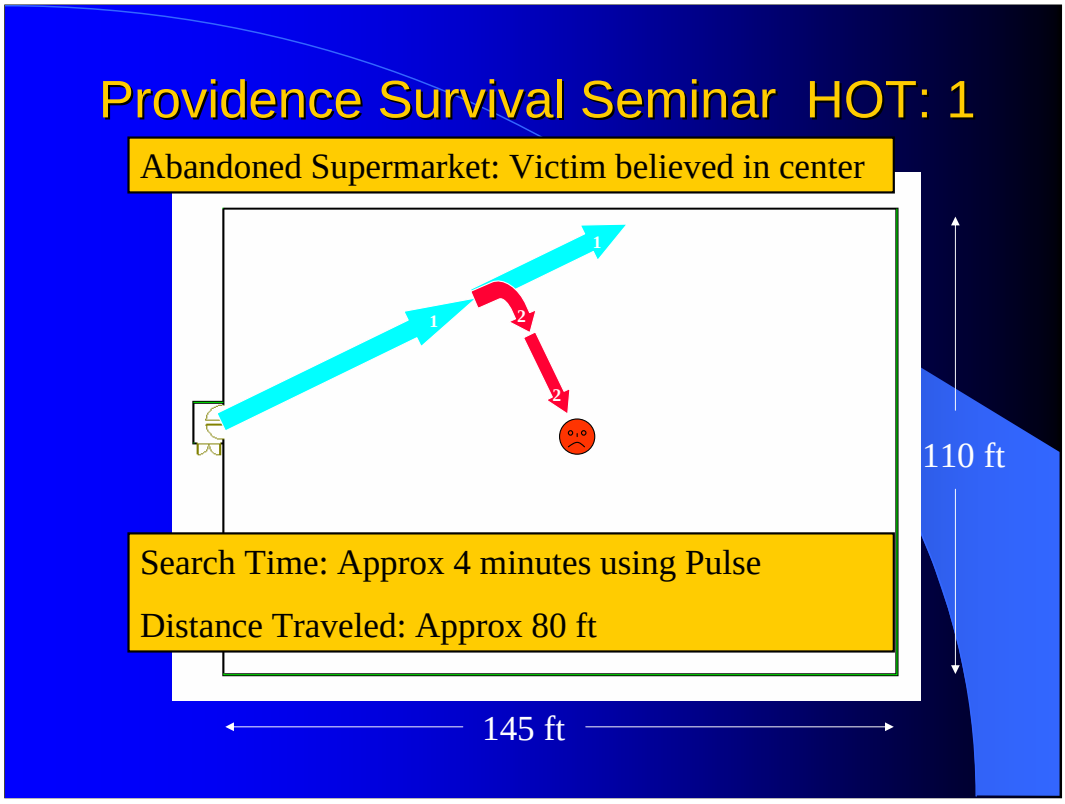
» The second instructor proceeded to the hall, and the Tracker began to pick up a small signal. We later realized that some of the ultrasound signal from the Beacon had escaped from the waste basket through the small grout spaces between the tiles. The ultrasound also escaped from the bathroom via the small crack under the door (which was about 1/16 inch).

The instructor began to go down the hall and found the first doorway to the right. When he opened the door, he pushed the Tracker into the bathroom and the signal level dropped to about zero.

» Realizing that the Beacon was not in that room, the instructor brought the Tracker back out into the hall, and the signal level was restored. The instructor then continued down the hall and found the second door. He scanned along the bottom of the door and found that the signal level was higher.

» He opened the door and the signal level increased considerably. He then scanned the room with the Tracker and headed straight towards the waste basket and found the Beacon.

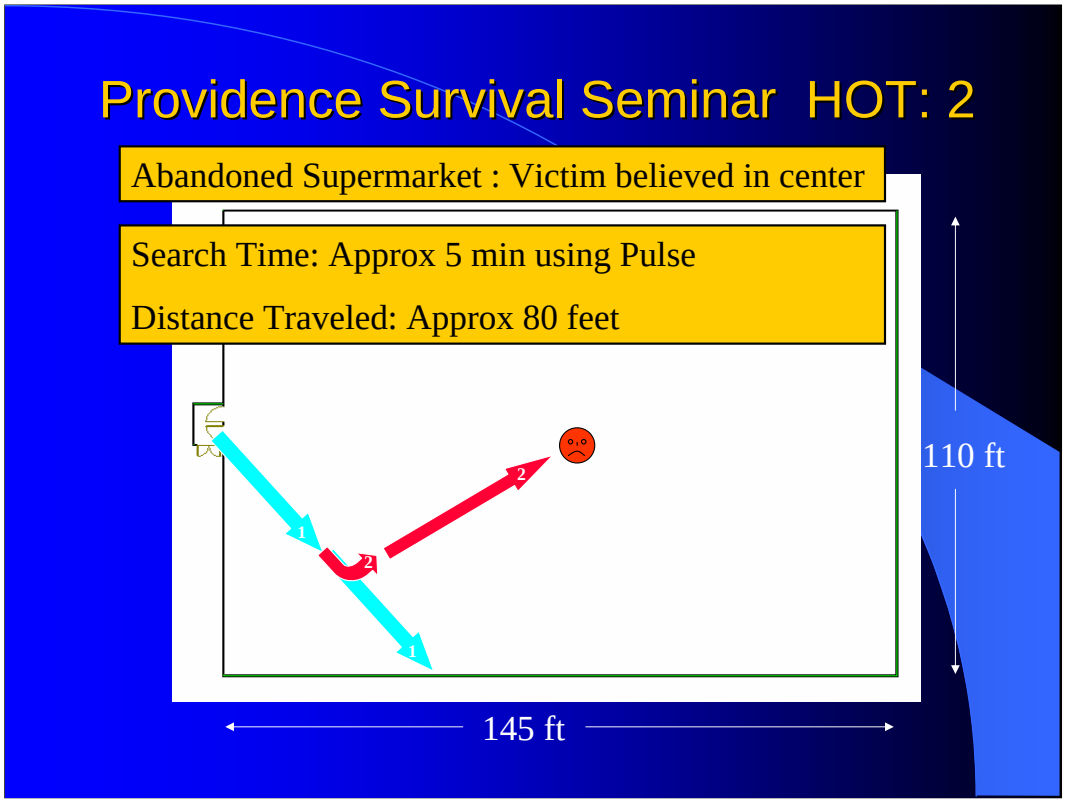
» The total time for the search was about 3 minutes.



For this test, the rescue team was told that there a firefighter had fallen through the roof near the center of the building. A Beacon in muted alarm mode (that is, ultrasound on, audible sound off) was placed on the victim. The team headed into the building, thinking they were headed towards the center of the room. In fact, they were about 30 degrees to the left. The team leader headed into the building and the firefighter #2 had a Tracker.

» As the group of five firefighters got about half-way into the building, firefighter #2 with the Tracker stopped the leader and insisted that they head towards the right. After a short discussion, the group headed straight toward the victim and quickly reached him.

» The distance traveled by the group was about 80 feet, and the victim was located in about 4 minutes.



For this test, a second RIT team was told that there a firefighter had fallen through the roof near the center of the building. A Beacon in muted alarm mode (ultrasound on, audible sound off) was placed on the victim. In addition, one instructor put ceiling tiles on top of the victim to camouflage him.

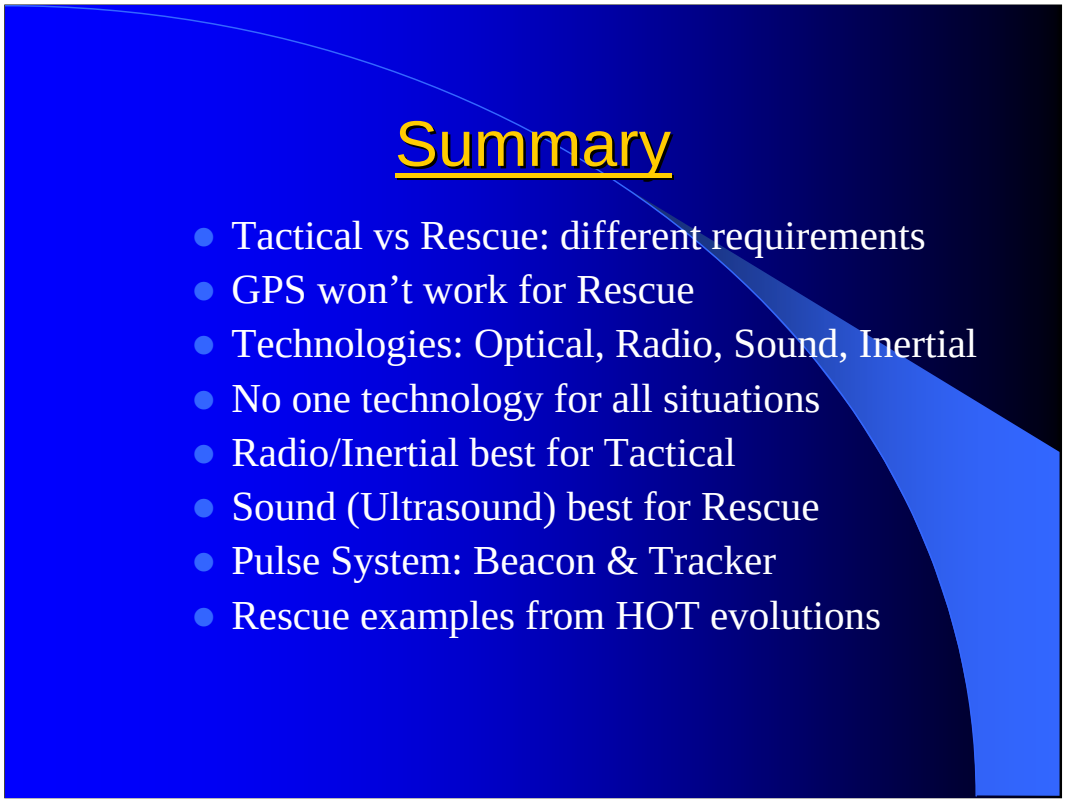
» The RIT team headed into the building, thinking they were headed towards the center of the room. In fact, they were heading about 45 degrees to the right. The team leader headed into the building and firefighter #2 had a Tracker. As the group of five firefighters got about one-third of the way into the building, firefighter #2 with the Tracker stopped the leader and insisted that they head towards the left. The group then headed straight toward the victim.

» The distance traveled by the group was about 80 feet, and the victim was located in about 5 minutes. After the group had rescued the victim, one instructor commented that he felt that if the group had used standard search techniques, they might never have found the victim.

In this wide-area search evolution, teams of three firefighters would head into the open building, with the team leader carrying the rope bag for the main rope, and the other two firefighters on tag lines off the main rope. The leader would first go about 10 feet into the building and the other two would search to the left and right, eventually reaching the leader. The leader would then go another 10 feet into the room and the process would be repeated, and so on. When the leader was at the 10-foot point, the PASS device of the victim was activated.

The slide shows that the team leader is at the 30-foot point and the other two members of the RIT team have just arrived to perform searches to each side of the main rope. Although all three can hear the loud PASS device, at this point they are unaware that they are within arms reach of the victim.

The search time for this photo took 18 minutes, using an activated PASS device. It is important to note that the search technique was not changed due to the presence of the PASS device. That is, the team would have found the victim in the same period of time had there been no PASS device.



To summarize,

» we have discussed two situations in which geo-location is important: Tactical and Rescue. There are different requirements for the two situations.

» We have looked at four different technologies for geo-location.

» We have found that no one technology seems to work for all situations.

» For Tactical situations, radio and inertial guidance seem to be the best choices.

» For Rescue, sound – and in particular, ultrasound – seems to be the best choice.

» We looked at the Pulse system, which uses an ultrasonic Beacon and a Tracker to locate a disabled firefighter.

» And we have looked at several Rescue examples from Hands-On-Training activities.