Running Head: UNDERGROUND DEVELOPMENT RISK ASSESSMENT

# A Risk Assessment of the Meritex Lenexa Executive Park Underground Development

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# Certification Statement

I hereby certify that this paper constitutes my own product, that where the language of other is set forth, quotation marks so indicate, and that appropriate credit is given where I have used the language, ideas, expressions, or writings of another.

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# Abstract

An extensive underground commercial development exists in the City of Lenexa called the Meritex Lenexa Executive Park. This development has three million square feet of underground space in a former limestone mining site. Space usage in the development includes offices, manufacturing, and warehousing storage including portions of the national archives. Hundreds of vehicles including full-sized semi-trucks enter this facility daily. The combination of site uses, content load, vehicular traffic, and limited access pose unique challenges for emergency response. This resulted in the problem statement used to generate this research paper:  The problem is that an underground commercial development exists in the City of Lenexa posing significant and unique life safety and property risks. The purpose of this research was to conduct a comprehensive risk assessment to identify the unique risks to life and property that exist in the Meritex Lenexa Executive Park. This was accomplished using descriptive research using the following four research questions:  What risks have been identified in other underground developments? What unique life safety risks exist for occupants and responders in the Meritex Lenexa Executive Park? What unique property risks exist in the Meritex Lenexa Executive Park? What current safeguards exist for occupants and property in the Meritex Lenexa Executive Park? The research for this paper was conducted using a review of existing literature and research, evaluating local data and information, as well as actual site visits and interviews. The results clearly found that risks common to any underground development were present with only some being overcome by existing safeguards. Recommendations were made in specific areas including improving communications, ventilation abilities, and occupant and responder training.

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# A Risk Assessment for the Meritex Lenexa Executive Park Underground Development

Every community has unique facilities or areas that pose special challenges for residents and emergency responders alike. Examples of some of these include areas with high population density, facilities with limited access, hazardous chemicals storage, etc. One such challenging area exists whenever any type of development goes underground. When such a facility or area exists, a normal facility inspection program or pre-plan may not suffice to provide needed information for occupant safety and responder preparedness.

The Lenexa Fire Department is no stranger to struggles with this very issue. The problem is that an underground commercial development exists in the City of Lenexa posing significant and unique life safety and property risks. This development is known as the Meritex Lenexa Executive Park. This area has been known as a potential site for unique challenges and problems since its initial development. The purpose of this research project is to conduct a comprehensive risk assessment to identify the unique risks to life and property that exist in the Meritex Lenexa Executive Park.

The research for this problem was accomplished using a descriptive research methodology. The research was narrowed down using four questions. What risks have been identified in other underground developments? What unique life safety risks exist for occupants and responders in the Meritex Lenexa Executive Park? What unique property risks exist in the Meritex Lenexa Executive Park? What current safeguards exist for occupants and property in the Meritex Lenexa Executive Park?

## Background and Significance

The Lenexa Fire Department is an all career department serving the citizens of the City of Lenexa, a suburban community in Johnson County, Kansas which is part of the greater metropolitan Kansas City area. The Department has five stations spread out over approximately 34 square miles serving a population that jumps from around fifty thousand at night to an estimated two hundred thousand at peak periods during the day. The Department is made up of 83 personnel across three operations shifts plus a supporting administrative staff. The Department is highly successful and professional having achieved such distinctions as being internationally accredited by the Commission of Fire Accreditation International (CFAI) under the Center for Public Safety Excellence (CPSE) since 2002 and earning an Insurance Standards Office (ISO) rating of two.

Located within the City of Lenexa exists an extensive underground commercial development called the Meritex Lenexa Executive Park. This development was created in abandoned limestone mining caves which are typically bored vertically into cliff faces. This type of development is common across the Kansas City metropolitan area which is home to the largest number of underground storage centers in the country (Hoffman, 1992). This particular development currently encompasses three million square feet of space with well over two million square feet already developed and occupied and plans for the rest. The existing caves and tunnels within this space have been developed into a multiple occupancy commercial structure housing office space, warehouse storage and even light industrial. One occupant of note is storage of a portion of the United States national archives. Another is Cavern Technologies which was featured on the Australian “60 Minutes” TV show and is described as “one of the most guarded and secured vaults in the United States” for data and information (Raletz, 2011).

The tunnels and caves making up this complex are large enough to allow semi-trucks direct access into the facility winding back through tunnels to full-sized loading docks. This combines a lot of potential problems into one confined area including hundreds of occupants, a large fire load, socially critical contents, vehicular traffic, and even hazardous materials like printing supplies and the fuel and fluids in the trucks and automobiles. When all of these exist in a normal commercial development, there is typically open sky and air around the various buildings and roadways. In this facility, everything is confined into what is essentially a single cave system with limited access.

It has long been recognized that the potential exists for a major incident within the underground development. Even a minor incident like a vehicle fire could quickly escalate with only the failure of a sprinkler or ventilation system resulting in massive property loss and even a mass casualty situation. Although all the members of the Lenexa Fire Department are familiar with the general location and layout of the underground complex, there is often much confusion on simple incidents on matters like communication and access. It is also believed that the typical occupant of the development has no more knowledge of needed emergency actions than would an occupant of a more conventional commercial park.

This research project was conducted as a requirement for the Executive Analysis of Community Risk Reduction (EACRR) course for the Executive Fire Officer Program for the National Fire Academy. The need for a risk assessment for the unique underground development clearly ties into multiple aspects of that course. The main course goal is to give the student the ability to strategically lead community risk reduction. The development of a comprehensive risk assessment of a unique target hazard clearly meets this goal. The development of the risk assessment also meets multiple U.S. Fire Administration goals. In fact, the first three goals all clearly apply to this research project:

- Reduce risk at the local level through prevention and mitigation
- Improve local planning and preparedness

- Improve the fire and emergency services' capability for response to and recovery from all hazards

A comprehensive risk assessment of a unique hazard like a large underground commercial development is clearly a preventative measure reducing local risk, is clearly a local plan enhancing preparedness and will definitely improve the agency's ability to respond to and recover from this particular hazard.

## Literature Review

A review of existing literature for this particular research project quickly found that recent information on this type of underground development is rare. To find recent sources of information, it became necessary to branch out to other types of underground developments such as subways, tunnels, and parking garages. Multiple sources of information were found on exactly this type of underground development but most dated back to the early 1990's directly after the Americold fire in Kansas City, Kansas. In this event, a cold storage facility built in an old limestone mine had a fire that proved impossible to extinguish conventionally. The fire free burned for at least six weeks (Hoffman, 1992). Eventually, 66 tankers of carbon dioxide were pumped into the mine and the entrance bulldozed shut (Hoffman, 1992). It took over three months after these actions for the fire to be reported as out. However, reports of elevated wall temperatures up to 100 degrees continued for several months even after these actions were taken (Germann, 1994). Fortunately, there was no loss of life but costs were estimated at 100 million dollars (DeBell, 1992; Horn, 1994).

The use of underground space in the Kansas City metropolitan area is not a new concept. The Kansas City area is home to the highest number of underground storage facilities in the nation (Hoffman, 1992). Storage began in old limestone mines as early as the 1930's. World

War II brought an increase in storage use for commodities and raw material storage. Commercial development and leasing began in the 1950's (Germann, 1994). What makes these facilities so attractive is that structural costs are reduced by as much as half because there is no need for an actual building. Typically, only partition walls and tenant finishing is required before move-in. Most of these facilities were mined using a "room and pillar" approach where massive pillars are left to support the ceiling in large open areas (Holdcraft, 1985). A year-round temperature consistently at 57 degrees helps to control energy costs with up to an estimated 80-90% cost savings (Germann, 1994). There are also typically minimal noise, dust, corrosion, and moisture problems for occupants (Holdcraft, 1985). The centralized location of the Kansas City area in the United States is also a big draw for this type of storage because of its centralized shipping location offering cost-effective access to markets nationwide (Horn, 1994).

Any type of underground structure presents complex and unusual hazards to life and property. Collins summarizes many of the obvious hazards in the following excerpt:

> Many ingredients for disastrous situations can be found in mines, tunnels, caves and other underground structures: remote or difficult access to entrances and portals; restricted spaces with minimal natural ventilation; potential for collapse of walls and ceilings; long horizontal or vertical travel distances to fresh air and the safety of the outdoors; the potential for sudden and massive flooding; the presence of atmospheric hazards like carbon monoxide, hydrogen sulfide, methane, oxygen deficiency, and harmful dusts; potential for disease-causing organisms; complete darkness in the absence of artificial lighting; and the possibility of fires or explosions, which may create a fiery oven channeling heat and smoke and killing victims and rescuers where they stand. (Collins, 2008)

Modern cave systems now realize the importance of sprinkler systems. These sprinkler systems are considered the best line of defense against underground fires, especially when combined with active alarm systems coupled to heat and smoke detectors. Debell (1992) cites two instances, one an arson fire and the other a conventional vehicle fire where automatic sprinklers contained both fires before they could spread. He did note however that the vehicle fire still produced enough smoke even with the sprinklers so that “firefighters nearly bumped into the vehicle before finding it” (DeBell, 1992). Flatley (2006) cites smoke from underground vehicle fires as the biggest threat since the average car incorporates all of the basic fuel types putting off large volumes of smoke which quickly bank down in the confined space. A truck fire deep inside a storage cave in Kansas City, Kansas took over an hour for firefighters to access due to the thick smoke even though a sprinkler system kept the fire contained until it burnt itself out (Hoffman, 1992).

The examples in the preceding paragraph show the importance of another major defensive measure, the ventilation system, which needs to be able to evacuate smoke, heat, and gases. Ventilation as pointed out before is often found to be a key in underground fire emergencies. In an underground tunnel fire in Los Angeles, firefighters had to use large positive pressure blowers, each moving 48,000 cubic feet of air apiece, to push smoke ahead of advancing firefighting teams (Reicher, 2009).

Along with sprinkler systems, standpipes are a common feature found in many of the underground developments. One noted feature common to the underground is that many of the water supplied systems often build up high levels of pressure and have to be regulated down. One facility was found to have pressure at their mains regularly at 175 psi (DeBell, 1992). In some underground facilities where sprinkler systems are not a valid or cost-effective option, high-pressure water spray systems are often utilized (Catchpole, 1993). This type of system was also recommended after the Channel Tunnel fire in 1996 as a high-pressure water mist system for use on train cars (Kirkland, 2002).

Occupants of underground facilities such as Meritex Lenexa Executive Park enjoy many protective features not found in most commercial buildings. There is typically little danger from weather events and little fluctuation in temperature due to the insulating nature of earth and rock. However, being underground means that emergency lighting is a priority. Another key feature is the need for a robust emergency ventilation system. Being underground, smoke and gases can quickly overwhelm the confined space environment leaving occupants no place to escape their effects.

Another key to occupant safety in the underground environment is compartmentation. The use of automatic fire doors is very important. DeBell (1992) found that the most common method of compartmentation was the isolation of areas that existed through the development of individual tenant space. Germann (1994) pointed out the advantages of creating both “safe” areas and isolated escape paths, both with independent ventilation systems and non-combustible structure and contents.  This was echoed by Liz Catchpole (1993) when she stated that a key aspect to subway safety in London was creating safe corridors for exit from the underground as well as compartmentation to contain the fire in localized areas.

Communication for occupants is vital. Most underground offices rely on hard-wired telephones which could fail if lines are exposed to an incident. One effective tool found to work in subway incidents involves having a public address system throughout the underground environment so information can be relayed and evacuation orders given (Herr, 1998). This type of system would help to eliminate occupant complacency to sounding fire alarms, especially if the facility is prone to false alarms. It could also be used to relay information to responders working within the facility during an emergency. Herr (1998) also found out that subway tunnels wired for cell phone use often supported the use of 800 MHz radios. This system could help occupants with the ability for cell phone contact and help responders who utilize 800 MHz radios.

Mine communications have seen some innovations in literature. A system available typically for mine use is called a “through-the-earth” transmission system and uses a low-frequency electromagnetic field for one-way communications. This system has the advantage of being wireless but can only be used to pass messages, not receive. Another through-the-earth wireless system allows for two-way voice and data communication however. Another system allowing for wireless two-way communication is “ComCell” technology which uses a minimally wired network to provide for two-way radio type communication throughout an underground complex. (Conti, et al, 2005)

Occupant training is a necessary part of personnel safety. However, most “employee training followed a general rule of ‘notify and evacuate’”(DeBell, 1992). Many mines however have realized the need to properly train workers since a relatively small fire may grow to a large fire by time emergency responders arrive on scene. This training often involves the proper use of fire extinguishers, water hoses, and firefighting procedures as well as proper communication (Conti, et al, 2005).

The idea of providing self-contained breathing apparatus (SCBA) for occupants was found mentioned several times in literature. However, it seems that most companies did not want to provide SCBAs because they preferred their employees to immediately evacuate. Debell (1992) found a common sentiment that “the presence of SCBA would encourage their people to stay and fight the fire". The use of occupant SCBA seems to be primarily restricted to the mine environment as is firefighting training.

Responders to underground development incidents often find themselves facing unique challenges that do not exist in normal commercial structures. The incidents can also involve a common hazard that is compounded by the underground environment. When operating below ground, "the above-ground, structural firefighting team is limited by lack of visibility, lack of communications and lack of time" (DeBell, 1992).

In 1991, responders to the Americold fire from the Kansas City, Kansas Fire Department found themselves facing dense smoke that pushed to the entrance of the cave. Visibility was non-existent. Ventilation fans were overwhelmed. "Firefighters used upwards of 80 percent of their air supply entering and exiting the smoke-filled cave, leaving only a few minutes per crew to actually do firefighting work" (DeBell, 1992). It was noted that the Kansas City, Kansas Firefighters were only wearing 30 minute SCBA bottles. Hoffman (1992) stated that the firefighters were only able to spend around five minutes advancing hose line because of the entrance and exit time required. Conventional communication systems did not work and a line of sight system had to be established using multiple firefighters to relay messages. Rope lines were used to lead firefighters into and out of the cave system.

Another problem that has been found to exist in caves is the effect of heat itself on the rock walls. As heat builds up, rock spalling is common and rock collapse is a real probability. "The hazards of confined spaces are also present as is heat-induced spalling that can drop tons of rock at a time" (DeBell, 1992). In the Americold fire, firefighters had to be withdrawn "after several personnel were struck by small pieces of stone and further reports indicated substantial drops of rock farther into the cave" (DeBell, 1992; Hoffman, 1992). DeBell (1992) also seemed to feel that this falling rock hazard was “perhaps the worst of those found in the caves.” Germann (1994) did point out that adequate ventilation releases heat and that “systematic heat reduction decreases the likelihood of spalling”.

Communication systems are a vital part of the firefighting effort. Radios especially are relied upon to relay orders, position, status, and even issue evacuation or mayday signals. The conventional radio system is useless underground however. Lawrence (2010) reports an inability to transmit or receive a signal utilizing a modern 800 MHz system when operating inside Type 1 and Type II buildings and especially in underground basements and garages. It should be noted that because of its computerized trunking ability, the 800 MHz system has quickly become the default, practical system for public safety agencies (Lawrence, 2010).

Special provisions are required to keep radio systems working underground. Repeater or amplifier systems are often used but require a separate power source. These types of systems also “can be negatively affected if active fire conditions exist in the building” (Lawrence, 2010). The use of vehicle repeaters for 800 MHz systems is also common and effective for conventional building reception enhancement but would offer no benefit to the underground cave type developments. Another alternative is a “leaky line” system that uses a continuous wire with exposed slots to act as a continuous antenna (Herr, 1998). In research, Herr (1998) found that a combination leaky line system with 800 MHz radios seemed to be effective in subways.

Hard-wired telephone systems with plug-in jacks are also possible although these tend to be found more in the subway underground environment. A similar option uses field phones on a reeled line which can be fed out as firefighters advance. A low-tech fix for portable radios underground is to use a string of firefighters in a line of sight transmission sequence. However, as tested in a subway environment, “this method of communication allows only for very brief messages because of distortion and confusion” (Herr, 1998). The Kansas City, Kansas Fire Department was forced to use this line of site approach at the Americold fire where “a radio relay system had to be set up using as many as four firefighters to repeat messages” (Horn, 1994).

One safety system that at least in the early 90’s was not common to all underground developments is a marking system. Cave systems typically involve a confusing array of tunnels and caves that can all look the same where even a detailed map may not always be helpful, especially in a smoke filled environment. DeBell (1992) found that several facilities used special marking systems that were color coded for both areas and exit paths. One of the systems utilized floor level reflectors. Underground mines often use reflectors or arrows with different colors indicating primary versus secondary escape routes. Other alternatives include spinning reflective pinwheels, laser pointers, strobe lights and rope lifelines with tactile and reflective directional indicators. (Conti, et al, 2005)

Throughout the literature, emphasis is placed on responder training. The responders must be very familiar with the facility before an emergency happens. “Pre-planning and walk-through tours have their place in the training process, but they cannot replace training in underground operations” (DeBell, 1992). Pre-planning procedures and necessary equipment is also very important. One example of pre-planned procedures and equipment was utilized by LA County firefighters in a tunnel fire. The firefighters dropped “bread crumbs” which were actually glow sticks to mark the exit path (Reicher, 2009).

The choice of safety equipment is also very important. One area of importance found in the literature is using the correct breathing apparatus. The Americold fire in Kansas City, Kansas quickly showed that thirty minute self-contained breathing apparatus (SCBA) bottles didn’t provide enough time to enter and perform work. Germann (1994) recommended the use of one hour bottles to allow for the time it takes to access the cave structure. This was echoed by Reicher (2009) when he stated that one hour bottles were called in for use during a tunnel fire in LA County.

Cave facilities such as the Meritex Lenexa Executive Park have a big advantage over more conventional commercial facilities in that there is little structure to actually burn. “Walls, floors and ceilings are solid rock and the common method of dividing spaces is through the use of masonry block walls” (DeBell, 1992). The main fire danger is to contents. This can be one of the main attractors for occupants and developers as insurance for the facility typically only needs to cover the contents. Contents are also well protected from weather and many other conventional commercial content concerns.

The same features that make the actual structure of an underground structure impervious to fire can also contribute to increased dangers for occupants and responders however. This was shown in a tunnel train fire in Austria in 2000 where an upward elevation of the tunnel acted as a chimney allowing smoke and fire to quickly spread upward and kill 155 trapped people (Prosser, 2008).

The same common themes are found throughout a broad literature review regarding underground developments. Overall, underground developments have a safe and effective track record. The main fire danger typically involves contents and due to the confined nature of the developments, poses major and immediate dangers to people and property. Access and egress, communications, visibility, ventilation, automatic suppression systems such as sprinklers, detection and alarm systems, and proper preparedness and training are mentioned again and again as keys to safety and effective response, as well as commonly anticipated problem areas.

## Procedures

The concept for this research topic came about as a result of the organizational policies of the Lenexa Fire Department of constant improvement and reducing community risk. The Meritex Lenexa Executive Park is known to all responders of the department as being a potential problem area but it is widely acknowledged that true knowledge on how to handle various emergencies there including use of existing systems is not sufficient. In order to tackle this problem, logical sequencing first realized a need for a thorough knowledge of the facility, it's supporting systems, and its hazards. This necessitated a hazard risk assessment which led to the purpose of this research project. Because of the acknowledged importance of this project, the research and data gathering quickly became an organizational wide project with many aspects delegated out to various personnel.

The first research question, "what risks have been identified in other underground developments" was answered solely through a detailed study of existing literature including studies, trade journals and research projects to include those from previous National Fire Academy Executive Fire Officer students. From this study, a summary of findings was then compared to the specific underground development specifications existing in the City of Lenexa to help answer questions two and three.

The second research question, "what unique life safety risks exist for occupants and responders in the Meritex Lenexa Executive Park" and the third research question, "what unique property risks exist in the Meritex Lenexa Executive Park" were both answered the same way. They required a combination approach utilizing both local information and existing literature. Similar to question one, a detailed study of existing literature including studies, trade journals and research projects to include those from previous National Fire Academy Executive Fire

Officer students was used to answer these questions from a general point of view. Then a local study of the Meritex Lenexa Executive Park was conducted using existing response records, site visits, and personal interviews with facility staff. The combination of these two approaches was then put together for complete answers.

The last research question, “what current safeguards exist for occupants and property in the Meritex Lenexa Executive Park” was answered solely at the local level. Because this question pertained specifically to the identified underground facility, only information gathered locally through response records, site visits, and personal interviews was appropriate.

The author of this paper conducted all of the reviews and studies involving published literature including studies, research projects, trade journals, and other media. The author also reviewed Lenexa Fire Department databases for specific incident and facility information pertinent to this assessment. Other Lenexa Fire Department personnel were utilized through much of the site data gathering process. This was done for two reasons: to efficiently allow for the completion of this large risk assessment in a short amount of time and also to actively involve the responders in learning about the facility.

In order to delegate part of the local data gathering, key areas of concern were identified and assigned, paying particular attention to personal areas of expertise but also making sure to involve all three operational shifts in the department. Lenexa Fire Department Battalion A was assigned to structural, egress, and specific content concerns. Lieutenant Tom Miller, the department Hazardous Materials coordinator, was assigned to review occupancy hazardous materials storage as well as dangers posed by frequent vehicle traffic into the facility including semi-trucks. Captain Randy Mains, the department technical rescue coordinator, was assigned to review the structural integrity of the facility in particular regards to possible collapse issues and capabilities of response. Captain Austin Mindedahl was assigned to catalog all means of entrance and exit from the facility, including those suitable for fire apparatus access.

Lenexa Fire Department Battalion B was assigned to the areas of communications and ventilation. Shift Battalion Chief Travis Vaughn was given the overall responsibility to identify current communication capabilities within the facility as well as test those capabilities. Chief Vaughn was assisted in this evaluation by the department Battalion Chief of Logistics, Rick Devries. Chief Vaughn was also given the responsibility to evaluate the current ventilation capabilities within the facility and identify perceived needs based on those capabilities. The Lenexa Fire Department Prevention Division staff was asked to also assist Chief Vaughn with evaluation of the ventilation system.

Lenexa Fire Department Battalion C was assigned the overall category of water supply and distribution including drainage. This included the categories of automatic sprinkler and extinguishment systems, standpipes, and existing fire department connections (FDCs). Battalion C was also given the responsibility of evaluating the facility utility services including gas, electricity (including emergency generators), and of course water as mentioned above. Shift Battalion Chief Scott Hoch was given the overall coordinating responsibility for the shift.

The Lenexa Fire Department Prevention Division was also tasked with several roles during the risk assessment. Prevention personnel were assigned the responsibility of assisting Battalion B with ventilation evaluation and recommendations. They were also tasked with evaluation and recommendations for the facility automatic alarm system. The Prevention Division was also tasked with assisting Battalion C with automatic sprinkler evaluation, specifically the ability to isolate and control different areas of the complex.

Facility cooperation at the Meritex Lenexa Executive Park was achieved by meeting with Ralph Nyquist, Operations Manager of the facility, as well as Bill Seymour, Senior Vice President of the facility. The Operations Manager was the main point of contact and interview subject whenever site visits were required or specific questions needed answering. It should be noted that the Meritex Lenexa Executive Park staff was extremely cooperative and open to the process of improving the fire department risk knowledge of the facility.

### *Assumptions and Limitations*

Research for this paper consisted in large part on sources that were unable to be directly verified as is often the case with media, especially when published on the Internet. The assumption was then made that the authors of these works acted with integrity and honesty when compiling their own research and publishing the results. An exception to this would be the Executive Fire Officer Program applied research papers obtained from the National Fire Academy's Learning Resource Center since the papers were known to be peer reviewed and subject to scrutiny.

Another limitation on many of the reference sources was age. Information specific to this type of underground development were abundant directly after the Americold fire in Kansas City in 1991 but has been limited in more recent times. This limits many of the older sources to general use rather than for specific data and statistics. The limited availability of current material also caused a branch out to related areas such as mines and subways so it is recognized direct application is not always possible.

The interviews utilized to gather specific site data rely solely on the honesty and knowledge level of the interviewee.  As is common with in-person interviews, it is assumed that the interviewee has the knowledge to produce accurate and complete information and the authority to release the information. Site visits also rely solely on the ability of the author and assistants to observe and gather data and it is realized that another researcher might notice additional information or interpret things in a different way.

Much of the data gathered in this research project also specifically applies to the Lenexa Fire Department and the Meritex Lenexa Executive Park. Data gathered from the records of another Fire Department would be expected to have different results. Also, although it is expected that many commonalities would exist between underground developments, it is possible that research conducted at a different site could produce different results dependent upon site specific logistics.

## Results

The first research question, “what risks have been identified in other underground developments” was answered solely through a detailed study of existing literature including studies, trade journals and research projects to include those from previous National Fire Academy Executive Fire Officer students. From this study, a summary of findings was then compared to the specific underground development specifications existing in the City of Lenexa to help answer questions two and three.

Existing information on other underground developments shows many common risks. The underground environment can also compound more common risks. These risks can include access, ventilation, visibility, communication, heat, rock spalling and collapse, water supply, and lack of knowledge and training. The following quotation taken from Collins (2008), although already used previously in the literature review, summarizes many of the risks found in underground developments.

> Many ingredients for disastrous situations can be found in mines, tunnels, caves and other underground structures: remote or difficult access to entrances and portals; restricted spaces with minimal natural ventilation; potential for collapse of walls and ceilings; long horizontal or vertical travel distances to fresh air and the safety of the outdoors; the potential for sudden and massive flooding; the presence of atmospheric hazards like carbon monoxide, hydrogen sulfide, methane, oxygen deficiency, and harmful dusts; potential for disease-causing organisms; complete darkness in the absence of artificial lighting; and the possibility of fires or explosions, which may create a fiery oven channeling heat and smoke and killing victims and rescuers where they stand. (Collins, 2008)

One of the most readily apparent dangers anytime you move underground is limited access. Whether cave, tunnel, mine, or underground building, access points are at a premium. Cave and mine systems typically contain a confusing array of tunnels and caves that can all look the same. A detailed map may not always be helpful in these environments, especially when smoke or other factors limiting visibility are involved. Lack of access points also makes it easier for occupants and responders to become trapped or cut off from the outside.

A common problem in the underground environment is the lack of natural ventilation due to the same access limitations noted above. Lack of access to the outside limits the ability to suitably ventilate. Often, the underground environment relies on mechanically driven air which can be compromised in an emergency situation. The lack of ventilation can present problems in multiple ways. The most obvious is the lack of life-sustaining air containing a suitable amount of oxygen and lack of toxins. The confined space nature of the underground allows for smoke and other toxic gases to build up to unacceptable levels.

Another problem which intertwines with lack of ventilation is the lack of visibility. The underground is naturally dark and relies on artificial light sources. These light sources, like the mechanical ventilation can be compromised in an emergency. Smoke in the confined underground space can also overwhelm any artificial lighting or directional markings further endangering occupants and responders. An example of all of this was at the Americold Fire in 1991 when members of the Kansas City, Kansas Fire Department found themselves facing dense smoke that pushed to the entrance of the cave. Ventilation fans were overwhelmed and visibility simply did not exist.

Flatley (2006) points out how quickly smoke from a simple vehicle fire can quickly fill up the confined underground environment and bank down. In fact, he cites smoke from vehicle fires as the biggest threat underground since the average car incorporates all of the basic fuel types putting off large volumes of smoke (Flatley, 2006). Hoffman (1992) gives another example of a truck fire inside a storage cave in Kansas City, Kansas which took over an hour for firefighters to access due to the thick smoke even though a sprinkler system kept the fire contained until it burned itself out.

Communication is a commonly cited problem in the underground environment. Most underground offices and facilities rely on hard-wired telephones which could fail if lines are exposed to an incident. Due to the very nature of the insulating rock, soil, and whatever else is between the facility and the outside, conventional wireless communications are useless. This is obviously a problem since the common communication methodology for modern responders is the two-way radio. One study reports that the 800 MHz radio system, common due to its computerized trunking ability, is unable to transmit or receive a signal inside Type 1 or Type II construction buildings, let alone underground (Lawrence, 2010). Use of these systems underground require specialized repeater or amplifier systems which require a separate power source and are susceptible to incident damage.

Time is not typically a luxury for any emergency incident. However, when an incident takes place underground, time becomes even more of an enemy. The very nature of the confined environment reduces the amount of time responders have to react and occupants and property have to survive. Even certain responder equipment such as self-contained breathing apparatus (SCBA) becomes a liability in the underground environment because they have such a short time limit, especially those using thirty minute bottles. In the aftermath of the Americold fire in Kansas City, Germann (1994) recommended the use of one hour bottles to allow for the time it takes to access the cave structure. This was echoed by Reicher (2009) when he stated that one hour bottles were called in for use during a tunnel fire in LA County.

Underground structures are often touted for their stability and resistance to damage, from weather to fire. The same features that make the structure impervious to fire contribute to increased dangers for occupants and responders when dealing with heat. The rock walls and insulating effects of surrounding material can cause the underground environment to become a virtual oven. A real example of this was a tunnel train fire in Austria in 2000 where heat, smoke, and fire were contained by the structure with the upward elevation of the tunnel acted as a chimney quickly trapping and killing 155 people (Prosser, 2008).

That same heat can have an effect on the otherwise impervious structural components common to the underground. As heat builds up, rock spalling is common and wall and ceiling collapse becomes a real danger. DeBell (1992) points out the danger of “heat-induced spalling that can drop tons of rock at a time”. The same Americold fire which has been cited numerous times in this paper already showed the danger when “several personnel were struck by small pieces of stone and further reports indicated substantial drops of rock farther into the cave" (DeBell, 1992).

A suitable water supply can be a challenge for any large structure. Place that structure underground and another level of risk becomes apparent. It is often difficult to supply adequate water from a conventional water system deep underground. This can make conventional fire control systems like sprinklers and standpipes hard to manage. Another problem often noted when moving underground is that supplied water often builds up high levels of head pressure and has to be regulated down. An example noted in literature found an underground main regularly at 175 psi (DeBell, 1992). This can be hard on normal equipment and personnel using these sources in an emergency. This is also important because automatic sprinkler systems are a requirement of NFPA 520 - Standard on Subterranean Spaces, so having these sprinklers adequately supplied by water is vitally important.

The last common hazard found throughout a study of underground problems deals with a lack of training and knowledge on the part of both responders and occupants. The mining community has begun embracing the need to properly train workers with multiple well publicized underground emergencies. It is also recognized that a relatively small fire may grow to a large fire by time emergency responders arrive on scene (Conti, et al, 2005). This lack of training for occupants can include emergency egress or shelter in place options as well as the correct use of critical equipment such as ventilation, alarm, and suppression systems. Lack of preparedness for responders could include lack of familiarity with the underground structure, actions to take in underground emergencies, and the use of specialized equipment in the underground.

The second research question, “what unique life safety risks exist for occupants and responders in the Meritex Lenexa Executive Park” was answered using a combination approach utilizing both local information and existing literature. The detailed study used to answer question one was used to guide the answering of this question from a general point of view. Then a local study of the Meritex Lenexa Executive Park was conducted using existing response records, site visits, and personal interviews with facility staff. The combination of these two approaches was then put together for a complete answer. The third research question, “what unique property risks exist in the Meritex Lenexa Executive Park” was answered in the same manner as question two utilizing a combination approach of both local information and existing literature.

Research into these two questions found that the risks overall to occupants and property were similar to other underground properties as answered in question one. When the risks begin to become unique is when you look at the current safeguards that exist in this particular development and their effects on the risks. This of course ties in to the last research question of this paper, “what current safeguards exist for occupants and property in the Meritex Lenexa Executive Park.” This last question was answered solely at the local level based on actual research at the facility in question. Because this question pertained specifically to the identified underground facility, only information gathered locally through response records, site visits, and personal interviews was appropriate.

Although the methods for answering the questions differed as described above, to clearly define the results of the last three questions, it became necessary to combine the results into an overall assessment since they all have bearing on each other. Questions two and three dealing with unique risks to either life or property quickly found that many of the risks were the same with some posing more of a hazard to life safety. The safeguards mentioned in question three helped determine what truly exists as hazards in the Meritex Executive Underground Park as compared to the overall risks discovered while answering question one through industry research.

Access to the facility was found to be better than anticipated. A map of the facility is included in this paper as Appendix A. A total of seven portals exist facing either west or south. Three of these are paved and are regularly used. The other four are gravel and could be difficult to access in muddy conditions by heavy apparatus. All seven could be used as pedestrian access or egress points and could accommodate smaller vehicles. One other access point is available in the form of a large diameter ventilation tube on the north east portion of the facility. This metal tube is capped by a vent cap with an exhaust fan that is mounted on hinges to allow access. However, a 125 foot vertical drop would mean extensive high angle preparation if emergency use was required.

Occupant egress in an emergency is similar to most large commercial buildings. Emergency lights are provided that run off batteries. Conventional lighted exit signs with battery backup point the way towards exit portals. Three separate emergency generators also automatically kick on during a power failure and keep every third overhead light fixture illuminated. Large painted signs with reflective paint also point towards the main exits. Although these are mainly used by delivery drivers finding their way out of the caves, they would also assist in an emergency.

Ventilation was identified by this project as a projected weak point. The normal day to day system is robust and more than provides for adequate circulation. Fresh air comes in through existing portals aided by a natural wind driven positive pressure. Four main exhaust fans are used at multiple points to remove stale air and further encourage fresh air to enter by creating negative pressure. Of these four exhaust fans, three are placed above existing portals. The last is the vertical tube vent mentioned above in the access section. Two of the portal fans are not regularly used but can be activated from the main facility control room located at the main entrance to the facility. The other portal fan and the vertical vent tube fan run continuously.

Each individual occupancy within the overall underground facility has at least one smoke removal fan that feeds out into the main corridors. However, if one of these fans is activated, a clean air source is still needed like an open door elsewhere within the occupancy. The theory is that a fire within an occupancy would be contents only due to the non-combustible nature of the facility. This fire would be contained by the sprinkler system and the smoke could be vented by way of the smoke removal fan into the main area where the main facility exhaust fans could purge the smoke and gases. The smoke removal fans can be activated locally at the occupancy itself or from the main facility control room at the main entrance.

Several shortfalls were found in the mainly environmental ventilation systems that exist currently. “Smoke from a small fire can quickly overload environmental ventilation systems and turn underground tunnels into zero visibility mazes” (Hoffman, 1992). None of the existing fans self-activate, they must all be manually activated. This goes for main facility exhaust fans as well as individual occupancy smoke removal fans. All smoke removal fans rely on the main electricity supply and are not powered when emergency generators supply the power. Multiple switches for occupancy smoke removal fans at the main facility control room were found to either not work or to be mislabeled. No active system exists for positive pressure supply of air. Positive pressure fans, if needed, would have to be supplied by responders and they are considered necessary in a large underground fire. The negative aspects of circulatory exhaust fans in a fire in contrast were pointed out when during an underground fire in Kansas City, Kansas in 1991, “the exhaust fans used to remove vehicle exhaust from the subterranean complex became so sooted from the thick smoke they failed” (Hoffman, 1992). It is also noted that the main facility areas do not have adequate smoke curtains in central corridors or caves making it difficult to channel exhaust smoke and gases down desired paths or block off uninvolved areas to keep the air clear.

Communications were found to be a definite potential problem area for this facility. Occupants rely on hard-wired telephones and computer access that can be compromised in almost any incident impacting structural components including heat or fire. The facility has no public address system. Emergency notification of an emergency outside of telephones and email would involve the alarm system which obviously does not give specific instructions or information. The automatic alarm system, like any other conventional system, can be activated automatically by sprinkler activation, smoke and/or heat detector activation, or by manual pull-stations. The system is monitored by an off-site monitoring company that transmits the alarm and any relevant data to the county emergency communications center. Occupants would receive notice of a potential emergency only by strobe lights and alarms.

Emergency responders to the facility also rely on inadequate communication technology. The conventional 800 MHz radios used by the Lenexa Fire Department do not operate inside the facility. The present system is outdated. It maintains a bank of older portable VHF radios at the main entrance to the facility. They are all programmed to a mutual aid channel. A leaky cable antenna runs throughout the facility. In theory, a conventional radio signal from the outside is received in the radio room, converted to mutual aid on the VHF system and broadcast throughout the facility via the leaky cable allowing portables to pick it up. Transmissions from the portables simply reverse the process. However reality has found that true and reliable coverage is spotty and outside contact cannot be counted on. Plus, the leaky cable is susceptible to damage much like the hard-wired phone lines.

Plans are already in place to upgrade the radio system for responders. This plan is being funded by the City of Lenexa. It will utilize a 700 MHz digital passive system allowing responders to utilize their normal assigned emergency talk-groups. The system will allow for radio coverage anywhere inside the facility. It is tentatively planned for installation in mid-year of 2012. However, at the time of this research project, only the old system was available.

Research into the dangers presented by heat-induced rock spalling and the possibility of subsequent collapse showed both a local and national response weakness. The caves themselves are considered secure from collapse under normal conditions. Wire mesh has been bolted in place over any areas that are considered potential weak points. The very nature of the rock walls is also considered to be non-combustible. Likewise, any individual occupancy construction is done using non-combustible materials such as masonry blocks. However, it is acknowledged that intensive heat could have adverse effects on the otherwise stable structure. The same structural components that make the facility non-combustible also serve to contain heat and allow it grow similar to an oven. Automatic sprinklers and ventilation are hoped to prevent this kind of situation by limiting content fire and evacuating heated smoke and gases.

Local research into training and response requirements for a possible collapse involved contact with the Mine Safety and Health Administration office in Topeka as well as the Occupational Safety and Health Administration (OSHA) regional office in Wichita. Both agencies admitted to not knowing who has jurisdiction over this type of underground facility built into old mines. At the time of this paper, the two agencies had agreed to meet and work through this oversight.

The underground facility is well supplied with water from the conventional municipal water supply. There are hydrants along the internal roadways spaced every three hundred feet with 2.5 inch discharges. The facility was noted during tests to have a high head pressure ranging between 110 and 130 psi at the hydrants due to its depth below the surface. However these pressures are still considered workable in firefighting conditions. The entire developed facility is protected by automatic sprinkler systems as well. An external fire department connection is available off of an adjacent surface road allowing the fire department to supply additional water to sprinklers.

The contents of the facility present a risk factor in themselves. Hundreds of vehicles including semi-trucks move throughout the facility daily. Each vehicle brings with it the normal hazardous materials of fuels, oils, and other fluids. Flatley (2006) states that smoke from a burning vehicle is the “biggest threat in underground facilities”. Additional hazardous materials exist in light industrial uses such as printing ink. However, there are no occupancies devoted to or storing overly high amounts of hazardous materials. Pure fire load is a big risk. Portions of the national archives are stored in the facility as are numerous records of other businesses. One business also is a dedicated computer server facility with banks of heat-producing computer equipment constantly running. The contents of the facility overall are considered to be the biggest risk since the majority of foreseeable emergencies would be as a result of an unplanned event with machinery or contents.

Training and awareness were found to be big risks areas for the underground facility, both for occupants and responders. Occupants receive no special training for emergency events and there is no published emergency action plan for occupants to follow. The underground facility is treated like any other business park where individual occupancies determine the preparedness levels of their employees. Responders were also found to be deficient in preparatory training. Awareness of potential problems is high due to walk-through type training and previous responses to the facility for minor incidents such as automatic alarms and medical calls and a vehicle fire. The location of the main facility control room housing the fire alarm panel and the communication system is well known. However, no specialized training has taken place regarding emergency access, ventilation, communication, underground fire characteristics, etc. Responder awareness tends to be just that, awareness for normal events but not prepared for major emergencies.

## Discussion

The results of the study while answering the four discussion questions shows a clear correlation to literature review findings. All of the risks found at the actual Meritex Lenexa Executive Park can be found mentioned elsewhere in literature as long as the research is broadened to incorporate different types of underground developments from subways to mines to underground storage and parking. The key to this research is identifying which risks have been reduced to acceptable levels by safeguards that are in place in the facility.

Access to the facility in an emergency situation was found to be better than expected with seven total portals at different parts of the facility plus a useable vertical ventilation shaft. Exit signs and both generator powered lighting plus battery backup lights aid in egress as do reflective exit pointing signs. Reflective signs like these however have been found to be less effective over time in mines, especially in heavy smoke, due to the accumulation of dust and degradation of the reflective surface (Conti et al., 2005). Studies have shown however that a more aggressive egress marking system may be required in the event of a zero visibility emergency. NIOSH describes several of these aggressive marking systems in a fire safety report including laser pointers, strobe lights, and reflective spinning pinwheels (Conti et al, 2005).

Ventilation was found to be a short-coming causing undue risk since much of the airflow relies on natural ventilation plus exhaust fans with no way to direct positive pressure flow during aggressive ventilation. The smoke removal fans in each individual occupancy are a positive but no dedicated fresh air source is available to resupply the area once the exhaust fan is utilized. All exhaust fans including the main portal fans require manual activation with many of the remote switches being mislabeled or not working. In comparison, Holdcraft (1985) calls for “automatic smoke-venting facilities”. Additionally, the individual smoke removal fans have no alternate power supply if outside power is lost. Smoke curtains are almost non-existent as well giving responders no way to control the path of smoke and gas removal.

The current communication system is a definite hazard. Occupants rely solely on hard-wired landline telephones or computer communication dependent upon hardwired lines. These are known to be potential fail points during an emergency affecting either the structure or the utilities. There is no public address system or way to mass communicate information or directions. One article cites a public address system as being an “effective tool found to work in subway incidents” “so information can be relayed and evacuation orders given” (Herr, 1998). In an underground fire safety report, NIOSH states that “it is imperative during an underground emergency that all persons, no matter their location, be able to get quick notification of the emergency” (Conti et al., 2005). The existing automatic alarm system will alert occupants in an emergency but only with a general strobe and alarm notification.

Responders have no current reliable communication method inside the underground facility. The normal 800 MHz radios carried by responders of the Lenexa Fire Department do not operate underground. This fact is supported by a study reporting “an inability to transmit or receive a signal utilizing a modern 800 MHz system when operating inside Type 1 and Type II buildings and especially in underground basements and garages” (Lawrence, 2010). The supplied VHF portables with leaky wire antenna inside the Meritex complex are spotty and unreliable. A replacement system is under development but is still months away from implementation.

The possibility of a cave-in or structural collapse is not believed to be a normal risk and steps have been taken to prevent any potential weak points from dropping rocks. However, it is known that an event producing large amounts of heat could result in spalling and a loss of structural integrity. “In limestone cave tunnels, ceilings and walls near intense heat will dramatically spall with large chunks of rock breaking loose” (Hoffman, 1992). No responder training has taken place on this possibility and it was discovered that even the national government regulatory agencies are unsure who has jurisdiction over this type of development.

The water supply for the facility is very robust and helps to reduce much of the risk found in some underground developments. Automatic sprinkler systems are in all developed areas and can be backed up by the fire department via a dedicated fire department connection. Hydrants are located internally along all the roadways spaced every three hundred feet with a static head pressure more than suitable for firefighting needs. This water supply, primarily through the automatic sprinkler system helps to reduce the risk of the heavy fire load brought about by machinery, stored materials, and vehicles.

A large amount of risk was discovered due to a lack of training and preparedness by both occupants and responders. Occupant training is dependent on each individual business and no comprehensive occupant action plan is made available. “Underground miners are required by 30 CFR 75.383 to walk escapeways and participate in fire drills every 90 days” (Conti et al., 2005). However, no similar requirements exist for occupants of business parks in decommissioned mines and no known fire drills take place at Meritex. Responders have only a general awareness of the facility and do not regularly train on emergency procedures specific to the facility or to the possible specialized conditions that could exist in an underground incident.

Based on the results and discussion, it is felt by this author that much needs to be done to reduce the risks to occupants, property, and responders. However, it should be noted that many robust safeguards do already exist and the remaining risks can be overcome once known and acted upon. Recommendations for possible risk solutions are listed in the last section of this paper. The work that went into the research for this project, particularly that on site at the facility utilizing other departmental personnel has already served to raise awareness and concern. It is not enough however to simply discover the risks, steps must be taken to overcome them and this involves continuous training and updating of plans and procedures.

The results of this research have clear implications for the Lenexa Fire Department. By identifying common risks to underground developments and comparing those to existing risks at the Meritex Lenexa Executive Park, validity was brought to concerns. Identifying safeguards and processes in place that already serve to reduce risk help occupants and responders to be aware of what is in place and what additionally needs to be done to bolster these safeguards. Comparing existing safeguards to identified risks also shows where work needs to be done to improve the hazards and to reduce the risk to life and property.

# Recommendations

For someone reading this research paper in the future, it should be realized that information in this paper may have changed substantially. In fact, one of the driving forces behind this research is that it will spur change and improvement to reduce identified risks and to provide for a safer facility and a better prepared response force. These anticipated changes mean that it is important for the spirit of this research to continue so that findings are updated, industry best practices are recognized and implemented, and newly identified abilities and procedures do not stagnate. This is especially important for the organization of the Lenexa Fire Department.

Below are some specific recommendations based upon findings both locally and through research of underground developments. These recommendations are meant to build upon existing safeguards at the Meritex Lenexa Executive Park. Implementation of recommendations may find that needs change or other steps become necessary. It is important that all involved stay adaptive and responsive.

- Provide improved methods for directional orientation, especially in zero visibility events such as those involving heavy smoke. Industry examples of these include lasers, strobe lights, guide lines or handrails, etc.
- Provide for positive pressure ventilation. This could entail the installation of additional equipment at the facility or could be mobile portable blowers brought in by responders.
- Smoke curtains should be installed to keep smoke and toxic gases better isolated to only a part of the complex and also give responders the ability to control their removal
- Existing smoke removal fans in individual occupancies within the development should be hooked up to auxiliary generator power and all switches should be repaired and correctly marked.

- Continue with plans to improve responder communication with the installation of the new 700 MHz digital passive system designed specifically for this location
- Give occupants of the facility access to the internal radio system so they have a communication methodology in the advent of shelter in place actions and a loss of hardwired phones and computers
- Install a facility wide public address (PA) system
- Develop an emergency action plan for occupants to follow in anticipated emergencies and follow this up with regular training
- Develop a comprehensive hazard response plan for the Lenexa Fire Department with supporting departmental policy. Train regularly on all anticipated emergencies, especially those outside normal operations such as cave-ins and underground fires.
- Follow up with the Mine Safety and Health Administration and the Occupational Safety and Health Administration to ensure that this type of facility is correctly identified and responsibility is taken for safety and training requirements.

## References

Catchpole, L. (1993, Dec.). Going underground. *Fire Prevention*. December, 1993. 24-24.

Collins, L. (2008, Jan.). Mine & tunnel emergencies: part 1 – introduction to rescue concepts & issues. *Firehouse*. 33(1). A18-A20.

Conti, R., Chasko, L., Wiehagen, W., Lazzara, C. (2005, Dec.). *Fire response preparedness for underground mines*. Cincinatti, OH: NIOSH. (Accession No.: 130369)

DeBell, J. (1992, June). *Fire protection in underground facilities* (EFOP ARP). Emmitsburg, MD: National Fire Academy. (Accession No.: 68709)

Flatley, C. (2006). Automobile fires in underground parking structures. *WNYF*. (2), 21-22.

Germann, M. (1994, July). *Improving underground fire protection in the Kansas City metropolitan area* (EFOP ARP). Emmitsburg, MD: National Fire Academy. (Accession No.: 80028)

Herr, J. (1998, January). *Underground communication systems for subway incidents* (EFOP ARP). Emmitsburg, MD: National Fire Academy. (Accession No.: 90160)

Holdcraft, R. (1985, May). Fire protection criteria for caves. *Fire Journal*. 79(3), 35-37.

Horn, R. (1994, August). *The effects of the Americold fire policy and procedure – a survey of municipalities and their underground storage facilities* (EFOP ARP). Emmitsburg, MD: National Fire Academy. (Accession No.: 80031)

Lawrence, J. (2010, August). *Limitations of 800 MHz portable radios and solutions for unreliable communications in some buildings and underground structures* (EFOP ARP). Emmitsburg, MD: National Fire Academy. (Accession No.: 136000)

Hoffman, J. (1992, June). Kansas: underground storage center challenges firefighters. *Firehouse*. 17(6), 78-80.

Hoffman, J. (1992, September). Trouble underground. *Fire Prevention*. 41-43.

Kirkland, C. (2002, April). The fire in the Channel Tunnel. *Tunneling and Underground Space Technology*. 17(2). 129-132.

Meritex (2011). Lenexa Executive Park. Retrieved from http://meritex.com/html/kansas_city.html.

NFPA (2008). *Fire Protection Handbook* (20th Ed.). Quincy, MA: National Fire Protection Association.

NFPA (2009, Dec. 9). *NFPA 520: standard on subterranean spaces* (2010 Ed.). Quincy, MA: National Fire Protection Association.

Prosser, A. (2008, Nov.). Going underground: a complete history of tunnel disasters. *Fire*. 101(1310). 22-24.

Raletz, A. (2011, Dec.). Lenexa's Cavern Technologies gets TV spot on Australia's 60 minutes. *Kansas City Business Journal*. Retrieved from http://www.bizjournals.com/kansascity/blog/2011/12/lenexas-cavern-technologies-gets-tv.html.

Riecher, A. (2009, May). Tunnel vision: Los Angeles County firefighters battle underground fire in a refinery tunnel. *Industrial Fire World*. 24(3), 14-17.

Thornburg, D. (2007, Sept.). *2006 IBC Handbook: fire and life safety provisions*. Country Club Hills, IL: International Code Council.

# Appendix A


PRAIRIE STAR PARKWAY
EXISTING PORTAL EMERGENCY ACCESS
FUTURE CONNECTION TO RIDGEVIEW
FUTURE SURFACE ROAD
SURFACE ACCESS ROAD TO PRAIRIE STAR PARKWAY (95TH STREET)
SECONDARY ENTRANCE PORTAL
STAGING AREA
PRIMARY ENTRANCE PORTAL WITH CENTRAL CONTROL STATION AND GUARD POST
BARLEAN'S 24,000 net sq. ft.
MAINTENANCE SHOP (3,000 S.F.)
CAVERN TECHNOLOGIES 9,000 net sq. ft.
BLACK AND VEATCH 43,300 net sq. ft.
CAVERN TECHNOLOGIES 35,000 net sq. ft.
VACANT 7000 net sq. ft.
WORLDWIDE WINE & SPIRITS 28,000 net sq. ft.
NARA STACK ROOMS VII-XIV
NARA RECORDS CENTER
NARA ICE CUBE 18,800 net sq. ft.
VACANT
PERFORMANCE PACKAGING
BYRNE CUSTOM WOODWORKING 15,000 net sq. ft.
KENNER BLVD
KERRY
LASER CYCLE 107,170 net sq. ft.
REMEL 137,500 net sq. ft.
MERITEX LOGISTICS I & II
NO-SPILL
POWER SALES
DOOLITTLE
KERRY
CEVA BIOMUNE
SUNDERLAND
PRIORITY ENVELOPE
PARTNERS KAN-VERTING
CANTEEN
LANTER
SERVICE PAK
RESTOR TELECOM 25,000 net sq. ft.
EXISTING PORTALS (EMERGENCY ACCESS)
LEGEND
DEVELOPED SPACE 2,232,645 SF
AVAILABLE SPACE 767,355 SF
TOTAL SPACE 3,000,000 SF
N
200' 0 200' 600'
SUBSURFACE CROSS SECTION
GBA
architects
engineers
MERITEX®
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