A Review of Current Practices for Providing Integrated Systems for Life Safety of Tunnel Occupants -- Application to SSC Tunnel Requirements

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In considering the question of the adequacy of underground and tunnel access/egress and related occupant safety issues, beyond the Federal Occupational Safety and Health Administration Standards, there are no universal standards or rules that apply. There are, nonetheless, a large number of underground and tunnel facilities in place that have each satisfied a set of safety requirements, applicable to that facility and conscientiously applied by responsible public officials and private parties. These existing examples of tunnels reflect an integrated systems design approach for the life safety of the occupants and provide an excellent source of hard data with which to test new or planned facilities.

The universally applicable Federal OSHA Standards set out the following requirements for worker safety. It instructs that:

There should be maintained at all times

1. A continuous supply of fresh air
2. An unobstructed path to a point of safety from any hazard
3. An emergency warning system.

For particular classes of underground space and occupancy, additional specific codified requirements have been developed, the best example of which is NFPA 130 which, though thorough in its context and representative of an integrated systems approach, is explicitly limited in its application to public transit subway facilities. More usual are such applications manuals as the U.S. Army, Corps of Engineers, Safety and Health Requirements Manual which reiterates the OSHA standards and codifies compliance for different conditions typically encountered in the Corps' Civil Works mission.

Applying the Federal OSHA standards to each unique underground facility requires that a more specific set of criteria be applied, derived from the OSHA standards, that can be summarized as follows:

<u>SAFETY IN OCCUPIED TUNNELS</u>

- Degree of Hazard
- Population at Risk
- Risk Reduction Mitigation
- Ventilation/Fresh Air Supply
- Clear path to Safe Location
- Monitoring & Warning System.

Applying the above will require an integrated systems approach to meeting life safety requirements in the occupied tunnels and this is properly begun with the examination of the specific conditions of occupancy, of assessable hazards, of ventilation systems and controls, of sensors, monitoring and communications systems and of egress and/or safe refuge considerations. To do this, one must look beyond the dominant single characteristic that all such facilities have in common -- i.e. that they are all underground -- to look particularly at how each differs from or may be similar to the other in 1) the population and type or training of occupants; 2) the sources of and risk level represented by hazards that could be present; 3) the sensor, monitoring and communications systems present and how they relate to the assessable hazards and the population; 4) the ventilation facilities and their controls provided and how they are designed to respond to a hazard by providing for the unidirectional movement of the smoke or gases that represent the hazard to a point of exhaust and, at the same time, a fresh air supply for the occupants to move into, effectively a zone of safety, and affording them the time necessary to reach a point of egress; 5) the provision for safe egress from the underground or to a point of safe refuge in the event of a hazardous event; and finally 6) the specific individual safety equipment and provisions available to the occupant population when in the tunnel.

To more specifically address the issues by looking at existing facilities and practice, a tabulation of representative tunnel types with regard to the above criteria has been assembled. Table 1 -- Comparison of Degree of Hazard and Corresponding Safety Considerations of Occupied Tunnels presents the information. Each is a relatively new tunnel; each is representative of a group of such tunnels; each has unique conditions to be satisfied that influence its design; and each reflects a clear and comparative relationship between population, assessable hazards, mitigation measures, egress to form an integrated system for life safety of occupants. The representative tunnel types are:

- o Railroad - Rogers Pass
- o Transit - Downtown Seattle
- o Highway-mined - Glenwood Canyon

- o Highway-subaqueous - 2nd Hampton Roads
- o Research-Equipment Enclosure - SSC
- o Water/Power - Calavaras
- o Sewer - Govalle
- o Flood Diversion - San Antonio
- o Flood Diversion & Sewer - TARP Chicago

All these tunnels are operational or in a late stage of completion except for the SSC. A comparative analysis of these tunnels, focussing on acceptable egress distance, reveals that the assessable hazard present in the tunnels has much to do with the selected safety design. Both highway and transit tunnels have relatively high levels of fire risk. Sewer and water conveyance tunnels as well as the highway and transit tunnels have smoke, gas or other oxygen-loss conditions to deal with. These tunnels, with these hazards, have ventilation that ranges from full transverse or longitudinal ventilation to none but natural air flow. They have sensor-monitoring systems that range from full TV surveillance, sensors and alarms and broad band radio antennae to no monitoring or signaling systems. The wide range of conditions and systems corresponds with the occupancy and training of the population involved. The best ventilation and monitoring/sensor/communication systems are employed where the largest populations occur which also represent occupancy by the more unsuspecting, untrained or otherwise unprepared populations i.e.. highway and transit tunnels. The least ventilation and monitoring/sensor/communication systems are provided to the least occupied tunnels -- tunnels occupied by trained maintenance personnel on scheduled visits and under full control and contact with a central control.

The population or occupancy is then a most significant variable. As noted above, large groups of untrained people in an underground environment when a hazard materializes represent a major concern requiring major investments in all safety-related systems. As a result, the highest order of ventilation, monitoring, communication, egress, etc. capabilities are provided within these facilities. Under these circumstances, acceptable egress distances have been set at 1100 ft., 650 ft., and 7280 ft. (1.4 mi.) for the examples cited.

Where the population/occupancy in the tunnel is carefully controlled, is made up of trained maintenance personnel who are provided with special equipment for their work including their own transport, even with a potentially significant hazard level, the concern for ventilation, monitoring, communication, etc. capabilities, in general, has been reduced and in some cases, has been left to portable units carried in by the occupants. Under these circumstances, acceptable egress distances have been set at 9.2 miles, 4 miles, 2.5 miles, 4300 feet, and 4000 feet. In each case cited it is significant to note that the accepted egress interval was set for reasons other than safety -- generally some physical operations reason -- except for the TARP project where the 4000 feet interval was set by the Chicago Fire Department based on its responsibility for fire and rescue during the construction.

It may also be observed that when tunnel occupancy occurs only for inspection and maintenance cycles, egress intervals are largest and the population is typically provided with a special vehicle or transport that in turn not only provides a rapid means to reach an exit if necessary but also transports various equipment including safety related items for the occupants.

Looking then at the SSC, the only facility in the array not yet constructed, it may be observed that the following pertains:

1. Population: The SSC will have occupants in the tunnels only during periods of inspection and maintenance. These occupants will be well trained in safety; will have appropriate medical certification for the duty; will enter only in pairs on a buddy system; will be logged in and out and be under control of and in constant touch with a person above ground; and will carry specified personal safety equipment.

2. Ventilation: The SSC tunnel will be occupied by people only when the beam is down and when the push-pull longitudinal ventilation system is operational. In the event of power loss, a redundant feeder is connected to the ventilation system. If a ventilation shaft is blocked, the system will adjust to maintain positive air circulation in the tunnel. The ventilation system will provide a flow of fresh air for a safe evacuation pathway while controlling the direction of movement of smoke or gases to their point of exhaust.

3. Hazard: In the SSC, fire smoke, and fire-produced gaseous products as potential sources of hazard are minimized by the lack of flammable materials in the tunnel. Fumes from a fire in an electrical unit and introduction of either helium or nitrogen gas into the tunnel resulting in the loss of oxygen are credible gas/smoke hazards. The ventilation system noted in 2 is sized for these events and sensors/monitors (as in 4) are present to identify such hazards at first instance.

4. Monitor/Sensor/Communications: The SSC tunnel is fully instrumented with sensors and monitored from a control center remote from the tunnel. The air is continuously sampled and abnormalities are reported and signalled in the tunnel when acceptable limits are exceeded. Occupants will be able to talk to control over 2-way radios, a telephone circuit, and hear central control over a loud speaker system. Occupant pairs can also communicate with other pairs while in the tunnel.

5. Access Control: Access into the SSC tunnels is totally controlled with interlocked gates and a tell-tale systems. Accidental occupancy is not considered a realistic concern.

6. Transport: Each occupant pair entering the SSC tunnel will have an electric transport vehicle (ETV). Being electric, it is not a source of combustion product gases (i.e. diesel, CO, CO_2, etc.). The ETV traction power is provided by an energized guide bar which receives its power from two independent power sources. In addition , the ETV has its own on-board power supply that is always charged that would allow the ETV to operate to a safe egress site in the event of loss of external power.

7. Egress/Safe Refuge: Egress and points of safe refuge in the tunnel are located at 2.5 mile intervals.

Weighing the tunnel safety conditions present in the planned SSC tunnel and comparing them with like considerations in the cited examples, the following observations may be made:

1. The SSC tunnel occupancy is most like that of the water transmission, sewer, flood control and sewer/flood control tunnels -- only occupied by trained personnel who are properly briefed and trained.

2. The SSC ventilation system is most like that of the transit and highway tunnels where the population and hazard risks are orders of magnitude greater.

3. The SSC tunnel assessable hazards are most like water transmission, sewer etc. tunnels. However, it is important to note that the assessable hazard conditions projected and planned for in the other tunnels are inherently and practically more dangerous to occupants than those projected to be present in the SSC.

4. The SSC monitor/sensor/communication systems are most like the transit and highway tunnels where the population and assessable hazards are materially greater.

5. The SSC Access Control is the most severe -- but most like the water transmission, the sewer, etc. tunnels.

6. The SSC occupant transport is most like the sewer and water tunnels but has a power supply redundancy three times over and does not produce potentially toxic fumes by its own operation as is the case in all other examples cited.

7. The SSC egress/safe refuge interval is less than for the railroad and the water transmission tunnels, equal to the sewer tunnel, on the same order as a highway tunnel and greater than the others.

Integrating and comparing population, ventilation, hazard, monitor/sensor/communication, access control, occupant transport and egress for the SSC and the cited examples, it is apparent that the as-planned SSC tunnel will represent a potential hazard source that is much smaller than the other tunnels cited for a population that is more tightly controlled, trained and monitored where it enters into an environment that is far more intensely monitored, with communications and transport significantly better than the other cited examples. The risk is lower; the preparations and plans more cautious; and the egress and places of safe refuge are about equal to or slightly greater than the other tunnels.

If any conclusion might be drawn at this point, it would be that the SSC is more conservative as now planned from a tunnel safety point of view, than are comparable facilities that are now in service.

Table 1

Comparison of Degr
and Corresponding Safety Considera

Tunnel	Function	Length	Distance between Exits	Cross Section or Diameter	Population: Number	Population: Occupancy	Population: Type	Population: Training & Procedures	Ventilation	Hazards: Fire: Source of Combustion	Hazards: Fire: Volume of Inflam.	Hazards: Fire: Type Fire	Hazards: Loss of Air	Hazards: Exit Blockage (Max. distance t escape)
Rogers Pass	Railroad, single track	9.2 mi	9.2 mi	Ø = 18 ft+ Nominal – (18 x 29)	6 to 8 10 to 20	•Normal (train in tunnel) •Maintenance	Train crew Maintenance crew	Briefed on walking out	Forced, longitudinal	Cargo & rail cars; Diesel fuel; Toxics	10^7 gal	Accident, fuel fed	Gas; Smoke; Loss of ventilation	9.2 mi
Downtown Seattle Transit	Bus transit	1.3 mi	1100 ft +	Twin, Ø = 17 ft	8000 to 10,000 per hour	Continual	General public	None	Forced, at stations	Diesel fuel; Rubber tires	300 gal	Accident, fuel fed	Smoke	1100 ft*
Glenwood Canyon Highway Tunnel *I-70*	Highway	3900 ft	2500 ft	Twin Ø = 40 ft Roadway is 15 x 40	200 to 1000/hr.	Continual	General public	None	Forced, semi-transverse (reversible)	Cargo materials; Gasoline fuel; Diesel fuel; Toxics; Vehicles	e.g., 6000 gal fuel tanker truck	Accident, fuel fed	Smoke; Loss of oxygen; Loss of ventilation	650 ft (to cross passage)
Calaveras Water & Power Tunnel	Water transmission	8 mi	4.3 mi	Ø = 18 ft	4 to 6	Occasional (annual inspection & maintenance)	Maintenance workers	Briefing; Buddy system; Log in/ log out	Natural (Open manholes at adits)	None	None	None	Lack of oxygen; Lack of ventilation	8 mi
Govalle Sewer Tunnel	Sewer interceptor & diversion	43,000 ft (8.1 mi)	1.0 mi to 2.5 mi	Ø = 8 ft	2 to 3	Occasional (maintenance & inspection)	Trained maintenance personnel	Safety lectures & briefing	Forced, longitudinal	Gasoline	Fumes	Explosion	Gas (H_2S); Loss of oxygen	2.5 mi
San Antonio Flood Diversion Tunnels	Flood water diversion	4.0 mi	4300 ft	Ø = 24 ft	4 to 6	Occasional (maintenance & inspection)	Trained maintenance personnel	Safety lectures & briefing	Temporary fans for maintenance cycle	Natural methane	Small, airborne	Explosion	Gas (Methane & CO_2)	4300 ft
Chicago TARP	Flood and CSO collection & transport	28 mi; (110 mi total)	4000 ft	Ø = 22–35 ft	4 to 6 per 5 miles	Occasional (maintenance & inspection)	Trained maintenance personnel	Safety lectures & briefing	Natural, (open manhole)	Gasoline, Methane	Small, airborne	Explosion	Gas (H_2S, Methane, CO); Loss of oxygen	4000 ft
Second Hampton Roads Tunnel	Highway	7280 ft	1.4 mi	Ø = 28 ft roadway is 15' x 28'	200 to 3000/hr.	Continual	General public	None	Fully transverse	Carried materials; Gasoline fuel; Diesel fuel; Toxics	e.g., 6000 gal fuel tank truck	Accident, fuel fed	Loss of oxygen; Smoke	1.4 mi
SSC	Research equipment enclosure	53 mi	2.5 mi	Ø = 10 ft	2 to 4 per 5 miles, 10 to 12 total – all in buddied pairs	Occasional (biweekly inspection & maintenance)	Maintenance staff with medical certification	Safety lectures & briefing; Buddy system; Personal safety equipment; Log in/ log out	Forced, longitudinal	Dry transformers; Electric carts; Circuit breakers	Non-flammable materials by spec.	Electrical	Smoke; Local loss of oxygen; Loss of ventilation	2.5 mi

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derations for Occupied Tunnels

lock- (Max. ce to ape)	Monitor or Sensors & Alarms	Access Control	Safety Provisions for Occupants	Applicable Code(s) for maint. & ops.	Determining Criteria for Exit Interval	Maximum Exit Distance (for Safety Analysis)	Remarks
	None	Uncontrolled but remote from population	Radio on train	Canadian & BC Province Safety Code	Ridge crossing, tunnel portals	9.2 mi	Shaft at tunnel mid-point has special elevator (shaft is 1350 ft). Throughout winter, exit house is snow bound. Owner: Canadian Pacific RR
ft*	TV surveillance; Sensors & alarms (Central control & monitoring)	Controlled at stations	Radio on buses; Surveillance TV at stations	NFPA 130 Fed. OSHA; Local Fire & Safety	Station spacing	1100 ft	* Jackknife articulated coach could block tunnel and escape passageway. Owner: *Metro Seattle*
ss ge)	TV surveillance; Alarm to nearby town Fire Dept.	Uncontrolled	Broad Band AM/FM radio antennae*	Fed. OSHA; AASHTO; Colorado OSHA	Portals; Ventilation; Cross passages	650 ft	* Operations center can broadcast instructions to radios of autos in tunnel on all frequencies. Owner: Colorado Dept. of Highways
	ODH Monitors	Locked access; Log in/log out	Radio with teams; Person stationed outside	Cal. OSHA	Lake to power house distance; Construction convenience	4.0 mi	Owner: Calaveras Water & Power Authority
	Gas monitor	Log in/log out	Vehicles; Radio with team	WPCF-MP9 Des. & Constr. of San. Sew.; State Dept. of Health	Sewer connections	2.5 mi	Owner: City of Austin
ft	None	Log in/log out	Vehicles; ODH monitors	Fed. OSHA; COE Safety & Health Requirements *Manual*	Ventilation during maintenance	4300 ft	Require max. HP engine of diesel truck used for maintenance and no. of occupants to be limited by operating spec. Owner: U.S. Army, COE
ft	None	Log in/log out	Vehicles; ODH monitors	OSHA; MSD Safety; Chicago Fire Dept.	Chicago Fire Dept. rescue for constr. period	4000 ft	Owner: Metro Sewer District
	TV surveillance; Air quality sensors	None	Broad Band AM/FM radio antennae*	AASHTO; Fed. OSHA; Virginia DOT safety criteria	Estuary width	7280 ft	* Operations center can broadcast instructions to radios of autos in tunnel on all frequencies. Owner: Virginia Dept. of Highways
	ODH, radiation, fire & flooding monitors; Vehicle location monitoring (Central control & monitoring)	Interlocked gates; Cardkey-type log in/log out	Radios with teams; Power backup on fans & transport; Refuges; Personal radiation monitors	Fed. OSHA	Length of technical sector	2.5 mi	* Hazards are potential smokey electrical fire (low combustibles) or a helium or nitrogen gas release Owner: U.S. Dept. of Energy