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Shelter-In-Place

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Introduction

This paper provides an overview the principles, procedures and efficacy of Shelter-In-Place (SIP) for emergency (chemical, biological and radioactive) incidents. To shelter in place or to evacuate is an important decision, and it is hoped the incident commander has sufficient data to make an informed and correct decision to protect the affected workers or residents. SIP is a protection tool that is used when there is reasonable assurance that movement of people beyond the workplace, residence, or school will endanger them more than allowing them to remain in place. A critical issue to address is whether SIP will provide adequate protection. SIP uses the building structure and its indoor atmosphere to temporarily separate people from a hazardous outdoor atmosphere. SIP is effective when the contaminant plume duration is short, infiltration into the building is low (tight building), contaminant toxicity and concentration are low, and when evacuation problems (communications, traffic congestion) outweigh its usefulness.

The decision to evacuate rather than to SIP is resource-dependent. The factors that influence an evacuation protective action are based on availability of transportation, population density, building demographics (i.e., urban or rural), and the characteristics of the event. Some of the characteristics that are considered for SIP include: the quantitiy and duration of the contaminant release, physical and chemical properties, meteorological conditions (atmospheric stability, wind speed and direction), population, the location of sensitive receptors, and the availability of structures that will provide adequate protection (Sorensen et al, 2004).

The National Institute for Chemical Studies (NICS, 2001) has examined chemical incidents where sheltering in place was used as a public protective action. It found no fatalities associated with the SIP orders and only a few additional injuries occurred that may have been related to the SIP order. It concludes SIP is an effective way to protect the public if there is insufficient time to complete an evacuation, or the chemical leak is of short duration, or if conditions would make evacuation more risky than staying in place (NICS, 2001). In addition to these conditions, SIP is often considered if the percieved health risk is minimal and the source is relatively far away from any sensitive receptors. Emergency responders must also consider the surounding area and the people affected, especially the high risk population, the elderly and very young, and those in hospitals, retirement homes, schools, day-care facilities, and prisons.

Types of Sheltering

When a decision to SIP is utilized as a protective measure, residents are asked to seek protection inside a building and to remain indoors. Rogers et al. (1990) characterized the different types of sheltering.

- **Normal sheltering** consists of taking refuge in an unmodified building with no additional levels of protection. This type of sheltering only involves going inside and closing all windows and doors, and turning off the heating, ventilating and air conditioning system (HVAC).

- **Expedient sheltering** is where people are asked to seek refuge in existing structures, and take measures to reduce the air infiltration rate into the safe room by taping plastic sheeting over windows and vents, taping over electrical outlets, and sealing doors and other openings with tape or wet towels. Expedient sheltering requires time to implement (20-60 minutes), but if preparations are made in advance and supplies are readily available, an air exchange rate of 0.2 air changes per hour (ACH) can be achieved.

- **Enhanced shelters** are pre-planned weatherized structures built with storm windows and doors; they typically have air exchange rates of 0.5ACH.

- **Pressurized sheltering** means that gas-particle filter blower units have pressurize the sealed room with filtered air. The blower produces a positive pressure in the safe room, so outside air cannot enter except through the air filter. Normal and expedient sheltering are the most commonly used sheltering techniques in community protection.

Air Change Rates

Air change and air leakage rates of buildings, homes and motor vehicles are relevant to estimating the efficacy of SIP. Prior to the energy crisis, building design allowed air leaks into the structure in order to maintain a healthy indoor environment with fresh, breathable air. With energy conservation, weatherization and increased building tightness became the norm (ASHRAE, 1975). Still, air leaks can occur at building joints and cracks and around doors, windows, electrical outlets, vents, and through penetrations that are not properly sealed at exterior walls, attached garages, attics, basements, or crawlspaces (ASHRAE, 2005). While commercial buildings often have forced air intakes to provide fresh air, residential homes depend largely on human activity, such as opening exterior doors or windows, for a fresh air supply.

Air exchange rates, infiltration rates and building tightness can be estimated with two methods: tracer-gas decay, and fan pressurization test (blower door). Tracer gas studies are considered the most accurate technique in measuring ventilation efficiency and infiltration rates, but they are expensive to run and the preferred tracer gas, sulfur hexafluoride (SF_6), is also a potent greenhouse gas use of which is largely banned under international agreements (Solomon et al, 2007). The blower door method uses a calibrated fan to pressurize or depressurize a building volume, and a pressure-sensing device to measure the pressure differential generated. The air flow, pressure differential, and building volume are used to estimate the ACH and building tightness. To normalize measurements across buildings, the ACH_{50} reported is the airflow in ACH at 50 pascals (0.2”WG) pressure difference (ASTM, 2003; Sherman, 2006). Smoke tubes and thermal imaging cameras are often used to locate and visualize the air leaks for caulking and weather stripping to reduce the air infiltration rate.

The ACH of residences can vary significantly, based on housing construction. Chan et al. (2003) used more than 70,000 air leakage measurements to relate infiltration with housing characteristics (floor area, year built, type of frame, and type of construction) and found that leakage was log-normally related to floor area, and that smaller, older homes had higher leakage rates than newer, larger homes. Sorensen et al. (2004) reported that older, wood frame houses had infiltration rates of 0.5-5.0 ACH, and Sherman (2006) found by using mathematical modeling that the leakage characteristics of energy-efficient buildings averaged 0.3 ACH, with a range of 0.1-0.8 ACH. Infiltration rates of structures have been shown to vary linearly with air temperature and air speed (Anno and Dore, 1978; Wallace et al, 2002). In vehicles, the air exchange rate increases with speed, dramatically decreasing the level of protection afforded: 0.5 ACH when stationary; 15 ACH at 35mph; and 40 ACH at 70 mph (Fletcher and Saunders, 1994).

The time to replace the air inside a structure is not a linear function of air exchange. Fletcher and Saunders (1994) calculated that 95% air replacement will occur in 12 hours at 0.25 ACH; 6 hours at 0.5 ACH; 3 hours at 1.0 ACH; and 1.5 hours at 5.0 ACH.

Safety Determination

Several studies have been conducted that evaluate the effectiveness of sheltering in place. Christy and Chester (1981) determined that by simply sealing the room with plastic sheeting and tape, the protection factor could be improved by 10 fold. Furthermore, Ward et al. (2005) determined that one to three portable, high-efficiency particle-arresting (HEPA) air cleaners can achieve 90% reductions in bioaerosols relative to conditions in which an air cleaner was not employed. Since the building structure “filters or reacts” with many contaminants, the protection factor may increase 15-50 fold, depending on physical and chemical characteristics of the pollutant. Prugh (1987) calculated that, for a typical U.S. dwelling with a 0.3 ACH, exposed to a 10-minute plume, the exposure levels inside the structure would be one-tenth of outside concentration and one-hundredth with taping. Jetter and Whitfield (2005) estimated the effectiveness of expedient sheltering in residences of participants who utilized the U.S. Department of Homeland Security guidance and found that the effectiveness was dependent on the extent and speed with which the subjects could perform the necessary protection steps.

Safe Rooms

Choosing and provisioning a safe room requires pre-planning and has been detailed by Blewett et al (1996). The location, space, and provisioning required depend on the type, severity, and frequency of the expected hazard. Generally, the safe room should be an above-ground-level, interior room of a well-constructed building, preferably with a water supply and toilet facilities. The room should provide 10 ft^2 of space per occupant and be provisioned with a disaster supply kit to last 3-14 days, depending on the nature of the emergency. The provisions should include: SIP procedures; tape; plastic sheets, premeasured and cut to fit all openings; food; water; first aid kit; medicines; medical information resources; flashlights; spare batteries; communication devices. Including phone, radio, TV, and email; bedding material; escape respirators; escape plan; emergency power; and air quality monitors for oxygen and toxic materials likely to be present. The procedures should specify how to SIP, and include how and where to gather, shut down HVAC, seal/tape all openings, monitor the situation, and escape.

The air quality in shelters was evaluated by Jetter and Whitfield (2005). They calculated the CO_2 and O_2 concentrations in sealed safe rooms would change during SIP, and thus limit the safe time for occupancy. In a typical sealed room that provided 10 ft^2/person, the CO_2 concentration rose to 16,000 ppm and the O_2 concentration dropped to 19.1% equivalent at sea level within three hours.

Jetter and Whitfield (2005) also tested 12 participants in SIP drills and found the mean time to construct the shelters was 35 minutes with a range of 20 to 60 minutes. Clearly, a major limitation of SIP is the amount of time required to implement the procedures. The time to implementation of SIP is lengthened if the on-site responders are more occupied with controlling the situation than informing the public. Also, they may be only required to contact some local agencies, such as the fire department or 911. More time is then needed to locate and notify the local authorities that have jurisdiction to activate an emergency response system. Once that system is activated, people will have to follow the different types of sheltering scenarios. Other compounding factors are that people tend to seek additional information before reacting to the SIP, or they may be skeptical of SIP effectiveness, or lack confidence in the officials making the decision, or they may decide to obey their instinct to flee rather than passively seek protection (Sorensen et al, 2004).

Conclusion

SIP uses the building structure and its indoor atmosphere to temporarily separate people from a hazardous outdoor atmosphere. The American Red Cross (2003) provides a step-by-step guide on how to SIP at home, work, school, or in your vehicle. A guide for small business has been prepared by the U.S. Department of Homeland Security to help businesses prepare, execute and recover from SIP orders (FEMA 2010), and OSHA (2010) has detailed evacuation plans and procedures for workplaces, all of which are available online.

SIP is effective when: the contaminant plume duration is short (< 2 hours); the contaminant toxicity and concentration are low; the infiltration into the building is low (tight building); there is reasonable assurance that movement of people will endanger them more than allowing them to remain in place; or there is insufficient time to evacuate. The limitations include the time required to give and respond to the SIP order, and the need for preplanning, drills, maintenance and inspection of safe rooms.

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