Shelter-In-Place

Reducing Risk From Toxic Impacts
For over 30 years, I have been conducting risk analysis studies on a range of facilities and transportation systems with flammable and toxic hazards. Having conducted hundreds of such analyses, I have evaluated a variety of risk mitigation systems and strategies to manage risks including complex mitigation systems to address hazards associated with highly toxic materials.

While Shelter-in-Place (SIP) has been a common mitigation strategy to mitigate public risk in the event of a toxic release from an operating facility, the use of SIP strategy for onsite personnel protection introduces additional complexities and considerations that should be accounted for in the strategy. However, in all the years I have been conducting risk analysis studies, I have found very few locations that have a good holistic approach to SIP. This became even more evident when, in discussions and deliberations during my participation on the Version 4 and Version 5 Committees to develop API RP 751: Safe Operation of Hydrofluoric Acid Alkylation Units, I was unable to identify a single document that described a comprehensive approach to using SIP to mitigate toxic risk.

My colleagues at BakerRisk have collectively leveraged their years of experience to develop this SIP guidance document. This holistic approach recognizes the need for early detection and timely response, design principles to minimize ingress of unignited gas (flammable or toxic) into the SIP building, and a plan to evacuate if the SIP is compromised. This guidance document closes a significant gap in the understanding and use of SIP as a strategy for risk mitigation.

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1 Introduction

The purpose of this BakerRisk Best Practice is to document general guidance for establishing a highly effective risk mitigation program for building occupants through sheltering in place with a reliable, effective fallback plan to mitigate risk in the event the shelter fails to provide adequate protection due to system failure or long duration exposure. In an Emergency Response Plan (ERP), occupants of Shelter-in-Place buildings (SIPs) may be directed to shelter-in-place for a number of reasons, but most notably sheltering occurs during a release of flammable or toxic gas that may impact site personnel. While this document focuses mainly on toxic protection measures due to an industry knowledge gap around this subject, it is important to understand that potential impacts of flammable gases should also be addressed, as applicable. Some systems that mitigate toxic impact (detection, HVAC isolation, and air tightness) would also be applicable to the mitigation of flammable gas impacts. In addition, buildings that serve as SIPs should be designed to meet required risk tolerance criteria for blast overpressure and other pertinent site hazards.

In most cases, this document also applies to flammable gas impacts. Buildings not designated as SIPs (evacuated immediately or shortly after a loss of containment event is detected) are not explicitly covered by this guidance document. However, those buildings should be addressed in the overall ERP, and aspects of the fallback plan described in this document are applicable to those buildings. This guidance document does not address outdoor or offsite populations.

Highly Effective SIP Strategy

1. Provide timely, reliable detection of toxic gases.
2. Provide timely, reliable isolation of ventilation systems to avoid ingestion of toxic gases.
3. Establish a leak-tight SIP volume to minimize infiltration.
4. Train personnel and provide instructions to ensure that sheltering activities are performed properly.
5. Provide an effective fallback (evacuation) plan.

Companies may have different names for a toxic SIP location, most commonly “safe haven.” It may be called a shelter/refuge, toxic shelter, toxic refuge, or other term. The guidance is applicable to any building in which personnel are expected to remain following a site event, but for the purposes of this Best Practice will be referred to collectively as an SIP from here forward. Key aspects of a highly effective toxic risk mitigation strategy for an SIP are as follows:

* Provide timely, reliable detection of toxic gases:
  1. Process Area / Outdoors - allows for faster HVAC isolation (prior to impact by the toxic plume) and provides critical input to decisions regarding evacuation if SIP degrades to dangerous conditions or after the plume clears (see Figure 1–1).
  2. At the HVAC inlet - ensures reliable, timely isolation of the HVAC system when the toxic plume impacts the inlet.
  3. At the building entry/exit point at grade - allows occupants to understand the hazard level outside of the door to make decisions regarding evacuation.
  4. Within the SIP - allows for informed decisions regarding evacuation from the SIP to a safe location.

* Provide timely, reliable isolation of ventilation systems to avoid ingestion (outdoor gases actively drawn into the building through the ventilation system) of toxic gases.

1. Automatic interlock HVAC isolation on process area and HVAC inlet detection.
2. Provide single-button manual isolation capability (a “red button”) within the location(s) where sheltering occurs to provide redundancy and allow for actions to be taken in advance of toxic gas impacts assuming process unit gas detection provides an early alert to building occupants.

* Establish a leak-tight SIP building as the primary barrier to minimize infiltration (outdoor air passively leaking into the building).

1. Address seals for windows, doors, HVAC ducts, and other penetration of SIP.
2. Use a smaller internal conference room.
3. Use a smaller internal conference room.

Signal to Isolate SIP, HVAC
before toxic plume reaches SIPs

Figure 1-1. Toxic Gas Dispersion & Detection

hallway, etc. to establish a secondary SIP barrier. Doing so can significantly mitigate impacts from doors being opened in the primary SIP barrier during a toxic emergency.

3. Address occupancy/room volume/tightness to ensure that any CO2 buildup and/or O2 depletion issue is understood and managed.

* Train personnel and provide instructions to ensure that sheltering activities are performed properly.

* Provide an effective fallback (evacuation) plan as part of the overall ERP since toxic gas may eventually infiltrate through the SIP barriers due to duration of release, system failure, late entries to the SIP, etc.

1. Provide indoor toxic gas monitoring for the SIP.
2. Develop procedures that identify evacuation thresholds and describe the process of transitioning from sheltering in place to evacuation.
3. Train personnel to take appropriate actions, including when and how to evacuate the SIP.
4. Provide communication channels between SIP and emergency response personnel who may
Develop procedures, provide training, and conduct drills to create a successful ERP program.

Additional enhancements can be implemented to reduce toxic risk or to improve comfort levels within the shelter location. These include the following:

- Implement a filtration/scrubbing system to reduce toxic concentration.
- Provide a supplied-air header with full face respirators or full air-supplied suits to allow long term occupancy by essential personnel (typically limited to control room locations, intended only for trained personnel).
- Enable temperature control systems to remain functional without causing any ingress or potential path of infiltration because the refrigerant is brought into the SIP room, so no ducts are required (commonly referred to as a split system).

This is particularly important when temperature control is required at sites with extreme weather conditions or for critical electrical equipment (instruments, computers, etc.), which is often located in a room adjacent to control rooms.

- Provide potable water, lavatory, kitchen, and other comfort enhancements.
- Include trended monitoring capabilities to provide information on outdoor conditions and hallways of the building if an interior room is used as the shelter.
- Clearly label shelter buildings and shelter rooms, including floor plans of the shelter that identifies the SIP boundaries.

Fortress Protective Buildings, LLC (FORTRESS) supplies a building product that brings together the best practices recommended in this document. With foresight taken with the design for personnel protection, FORTRESS is designed to protect occupants from exposure to flammable and toxic gas ingress from unignited materials reaching the building. This protection capability is incorporated into the building through three features:

- The design and construction of the building shell with limited gaps to reduce the potential for hazardous gas ingress.
- A system to monitor for hazardous gases in and near the building, with controls to close HVAC inlets and alarms to notify occupants.
- An SIP room with systems and controls to provide a safe environment for occupants to remain for long duration events.

Building Design Features to Minimize Gas Intrusion

The reinforced concrete walls, roof, and floor of each FORTRESS module provides a very effective barrier against gas ingress. The most obvious leak path, the joints between modules, have been designed to minimize leakage. Tests have shown that the building infiltration rate is less than 0.1 ACH with a 5-mph wind. At the door, a mud room or vestibule provides two doors at each entry, thus preventing ingress of outside air when one door is open (essentially an air lock). In addition, gaskets and door seals at the main building door, as well as the door to the shelter room, are also designed to reduce air ingress.

Monitoring and Controls System

A monitoring system is included in FORTRESS to provide occupants with accurate information concerning potential hazards from flammable and toxic gases and to automatically shut down HVAC systems that may pull outside gases into the building. In addition, a manual “red button” shut down option is located at the panel for manual intervention, if required.

- Detectors are chosen based on the chemical hazards specific to each site. They are placed at the air intake, at the door level outside the building, inside the mud room, inside the main building, and inside the SIP room.
- Concentration values of interest are monitored from within the SIP room.
- The monitoring system includes a detailed Graphical User Interface (GUI) developed specifically for the building layout to indicate concentrations at different locations.
- Upon detection of hazardous gases at the air intake, the HVAC system and exhaust fans shutdown and dampers quickly close to isolate outside air from the building volume.
- System is designed to provide reliability greater than 99%.

Shelter Room

Most FORTRESS buildings are designed with a shelter room that will maintain a safe environment for occupants for a duration of several hours, even if the building is impacted by an acutely toxic cloud that is 100 times the lethal concentration. The shelter room has minimal penetration from other rooms or outside the building and is isolated from the building HVAC system to prevent ingress of toxic gases through the normal HVAC circulation system, which enables the building to maintain an infiltration rate of less than 0.03 ACH. Air inside the shelter room is heated/cooled via its local split system HVAC unit.

In addition to monitoring for toxic gas in the shelter room, air quality is also monitored for increased carbon dioxide levels, increased temperature, and oxygen depletion. In order to address carbon dioxide accumulation and oxygen depletion concerns, the system automatically initiates the supply of fresh air for shelter room occupants as needed. The addition of clean air into the shelter room causes air to preferentially flow out of the shelter room, further reducing toxic gas infiltration and providing a carbon dioxide purging effect as well as the addition of oxygen.
2 Toxic Gas Detection

To be effective, toxic gas monitoring should be provided in these areas:
- Ventilation intake of the SIP building
- Inside the SIP building
- Inside the SIP room (if applicable)
- Process areas, especially in areas where releases are most likely

Figure 2-1 shows how toxic gas detection in these areas affects the mitigation effectiveness of an SIP.

The most important location for toxic gas monitoring with respect to establishing an effective SIP is at the ventilation system intake of the building. Without toxic gas monitors at the ventilation intake, a highly reliable ventilation system isolation strategy cannot be implemented. Detailed design should account for site and SIP-specific considerations that can only be evaluated on a case-by-case basis; however, some high-level considerations are summarized as follows:
- High availability and reliability and quick response time gas detection and HVAC isolation
- Practical concentration threshold (avoid spurious HVAC isolation from low concentration impacts)
- Selection of detectors for specific toxins of interest (avoid gas detector’s failure to detect due to excessive concentration)
- Coverage of all applicable significant toxic hazards

Because it is possible for the SIP building and room to eventually become dangerous (HVAC isolation failure, doors opened by “late comers,” excessively high concentration impact, toxic cloud duration, etc.), it is important for the SIP occupants to have an effective fallback plan as part of an overall ERP. One critical aspect of an effective fallback plan is to have toxic gas monitoring within the SIP building and SIP room, which allows actions to be taken as conditions degrade.

To take full advantage of the safety afforded by an SIP, it is important for occupants to remain within the SIP for the period that it continues to provide a safe environment. However, providing proper Personnel Protective Equipment (PPE) enables occupants to evacuate the SIP before it becomes dangerous to remain in place. It is important for concentration thresholds to be established and understood by occupants of the SIP, which is easily done through alarms on the SIP’s indoor toxic gas monitors. Without this understanding, occupants may evacuate a safe SIP environment into a lethal external environment. The lack of pre-established concentration thresholds and response actions may also result in occupants remaining within the SIP as the conditions become too dangerous to stay. Proper training and periodic drills help to ensure that SIP building occupants understand these concentration thresholds.

In addition to toxic gas monitors at ventilation intake and within the SIP, it is essential to also provide reasonably thorough toxic gas monitoring within process areas of the plant. Providing toxic gas monitoring in areas where releases are most likely (pumps, compressors, load/unloading areas, etc.) improves the likelihood that the hazard will be detected before the SIP is impacted. This allows ventilation to be isolated to reduce toxic ingestion, and equally as important, assists in determining where the release occurred.

Figure 2-1. Flowchart of Toxic Release and SIP Mitigation
Additionally, the presence of a sufficient number of gas detectors near the release source can enable the emergency response personnel to know when it is safe to evacuate the SIP after the release has been isolated or the inventory of toxic material has depleted. Area detectors also ensure that personnel are made aware of toxic gas releases in their work areas and allow personnel to take appropriate actions in response to the hazard.

Process area monitoring should provide real-time concentration readings to emergency response personnel so they can provide helpful advice regarding evacuation routes and mustering points. Toxic emergency procedures should clearly identify communication capabilities and directions for SIP occupants to make informed evacuation decisions by discussing options with emergency response personnel prior to initiating evacuation. Information provided by process area toxic monitoring may also be used to identify the release location enabling isolation to occur more quickly.

### 3 SIP Ventilation Isolation

Unless the ventilation system is always operated in 100% recirculation mode (no outside air is drawn into the ventilation system) or the ventilation system is scrubbed, it is imperative that the system be reliably isolated in a timely manner (<30 seconds) if a dangerous concentration of toxic gas reaches the HVAC inlet. This function is best accomplished through automatic HVAC isolation to minimize response time and maximize reliability. While system isolation can be manually initiated, it is less reliable and an activation delay would allow some amount of toxic gas to be actively drawn into the SIP before the ventilation is isolated. However, automatic systems should allow for manual isolation to allow early activation based on preliminary information on multiple process area alarms or if the system fails to initiate shutdown automatically.

The delay of HVAC isolation could severely degrade the effectiveness of the SIP, especially if any of the following conditions are applicable:

- The impact is from a very high toxic concentration
- The delay between impact and HVAC isolation is long (minutes instead of seconds)
- HVAC provides a direct path from outdoors to the interior room where sheltering occurs

SIP ventilation isolation may be accomplished by tripping fans and closing the dampers that allow outside air (makeup) to the system. Alternatively, the system can be placed into 100% recirculation mode. The advantage to complete shutdown is that it eliminates differential pressures that could otherwise serve as significant leak paths for the toxic cloud to enter the building. For example, fan suction may draw some amount of outside air into the SIP even though the suction damper is closed. Once activated by the automatic interlock and/or backed up by manual activation capabilities, toxic emergency response mode should not be limited to the main HVAC system but should also trip exhaust fans and close dampers on building exhaust locations (assuming it is safe to do so). Special consideration should be made for laboratory exhaust hoods, which could have their own hazards associated with shutting them down.

If the ventilation system uses a split system or other type of completely internal (enclosed within the boundaries of the SIP) temperature control system, then it can be left running during a toxic emergency. Having such a temperature control system may be critical for buildings with significant heat sources (e.g., computer rooms) and buildings that are vulnerable to becoming uninhabitable due to excessive temperature for other reasons. The temperature control system shown for the interior room in Figure 5-1 is an example of an internal system that could remain in service during a toxic emergency and would allow climate control to be implemented without degrading SIP performance.

### Comparing Toxic Monitoring at HVAC Inlet vs. Indoor Rooms

It is not as critical for indoor toxic gas monitors to have as short of a response time as the ventilation intake monitors because indoor concentration will not rise as quickly as the concentration at the ventilation intake (outdoors).

It is important that the indoor toxic gas monitors are maintained to be reliable and are appropriate for the toxins of interest (toxins with potential to cause dangerous concentrations within the SIP).

It is not as important to establish interlocks or alarms on indoor toxic gas monitors, as occupants who are sheltering in place would almost certainly pay close attention to the monitors.

Comparing Toxic Monitoring at HVAC Inlet vs. Indoor Rooms
4 Leak Tightness

The potential impact of a toxic cloud on occupants of an SIP depends on the concentration of toxic gases that accumulate in the SIP. Once HVAC is successfully shut down or placed into 100% recycle mode, then the effective infiltration rate is what determines indoor concentration for a given toxic impact scenario. The lower an SIP's effective infiltration rate is, the slower the rise of indoor toxic gas concentration will be. Along with a slower concentration rise comes lower toxic dose and lower occupant vulnerability.

To achieve extreme leak tightness, it is preferable to establish an interior room as the shelter location (secondary SIP barrier). It is still a good practice to make the balance of the building envelope (primary SIP barrier) as leak-tight as practical, but the protected volume of an interior SIP room can be kept much safer than the bulk of the building. Figure 4-1 provides an example floor plan of an SIP that uses an interior room as the shelter location.

Advantages of an interior SIP room include the following:

- The inner room has virtually no differential pressures due to wind, which reduces infiltration rates.
- An interior room can be made extremely leak tight if primary leak paths are addressed.
- Typically, there are a manageable number of ventilation ducts that can be sealed in a short period of time if people are trained and supplies are provided.
- It may be practical to reduce the effective infiltration rate by adding clean air into a room if the room is fairly leak tight, unless the volume is very large. Supplying clean air to an entire building is less practical due to the volume and because differential pressures caused by wind can overwhelm the air flow and result in nearly the same infiltration rate.

The presence of operable windows within an SIP is inherently less safe than having none, and they should generally be eliminated/made nonfunctional to avoid rapid SIP degradation in a toxic emergency. If the interior room SIP has windows (also should not be operable), and they are not leak-tight, then it is important to provide training and supplies for occupants to seal the windows in addition to doors once all occupants are in place. This action helps address the possibility of degraded gasket conditions.

- An interior SIP room is more effective if it is intentionally designed to have no direct paths to outdoor air, such as:
  1. No exterior walls
  2. HVAC system for room has no fresh air makeup
  3. HVAC system is not shared by other parts of the building

The potential impact of one or more “late comers” is dramatically reduced because even if a significant amount of toxic gas enters the main building (primary SIP barrier) while the doors are open, the concentration at the SIP room door would be much lower than the outdoor concentration and there would be minimal wind-driven flow into the SIP room.

Figure 4-1. Toxic Shelter Building with Interior Room
5 Ventilation System Design

Occupied buildings are required to provide fresh air to avoid issues associated with carbon dioxide buildup and oxygen depletion. This fresh air makeup requirement means that nearly all SIPs have a direct path for outside air to enter into the building and likely also provides a direct path for outside air to enter the interior SIP room (comes from stack on roof through the fresh air isolation damper for the example building shown in Figure 5-1, which shows the main ventilation supply in yellow, the return system in blue, and exhaust systems in green). However, if a building is being explicitly designed to provide an effective toxic SIP, the ventilation system can be designed to optimize SIP effectiveness by including the following aspects (Figure 5-1):

- Provide leak-tight dampers that isolate all outside air supplies from portions of the building that constitute primary or secondary barriers of the SIP.
- Provide split system or other internal temperature control system for all areas where temperature control is desired or necessary during a toxic emergency.
- Design the interior room ventilation system to be independent of the primary system with no outdoor makeup or use only an enclosed air conditioning system within the interior room.
- Provide leak-tight dampers to isolate SIP room from the remaining building (not applicable in the example building because it only has an interior air conditioning system).

It is important to ensure that the SIP room (secondary barrier) will not create a dangerous environment due to oxygen depletion or carbon dioxide accumulation. This can be accomplished by limiting occupancy for a given SIP volume and/or providing a clean air supply to the volume. Calculations of oxygen and carbon dioxide concentrations in an occupied volume with minimal air exchange are straightforward. They show that carbon dioxide accumulation is the limiting item (creates a dangerous condition before oxygen depletion does). As a general rule, as long as the SIP is not “crowded,” it will not become a dangerous condition within several hours. However, calculations should be performed in advance to verify this. Equipment can be provided to reduce carbon dioxide and to generate oxygen if necessary.

6 Additional Mitigation

Some toxic gases may be effectively mitigated by implementing a filtration or scrubbing system. It may be incorporated into the inlet of the HVAC system or it can be used in recirculation mode. Drawbacks to the inlet design include the following:

- Concentration of toxins in the air challenging the system is dramatically higher, which may rapidly saturate the filter/scrubbing system.
- Since it draws outside air into the building, if the filtration/scrubbing system malfunctions, the conditions within the SIP can quickly degrade.
- The system may always be online, which could require more frequent maintenance.
- Drawing air through the scrubber may create a differential pressure in the building that preferentially pulls air through building cracks, doors, windows, etc.
- Some scrubbers require an activation time that can take several minutes to initiate, making the scrubber ineffective for rapid isolation of toxic ingression unless the HVAC is isolated.
A filtration/scrubbing system that is used in recirculation mode is only impacted by low concentration toxic vapors, so it would be less likely to become saturated, and because it draws no outside air into the building, even if it malfunctions, it would not degrade conditions. One drawback to a recirculation system scrubbing design is that it would not pressurize the SIP, so it does not prevent or reduce infiltration rates.

In some cases, it is necessary for key personnel to remain in place even after conditions within an SIP degrade to dangerous levels (typically only true for control rooms). In such cases, a clean supplied-air header may be provided with full-face respirators. In extreme cases, where the toxin may enter through the skin, clean air may be provided to positive pressure suits (see Figure 6-1). Supplied air systems may be supplemented with SCBAs to allow manual actions to be taken in the field, as necessary (see Figure 6-2).

To ensure that such systems remain highly reliable, the design should accommodate the maximum number of personnel who may use it for prolonged events. To limit the amount of air required, other contingency plans can be considered.

The general approach (shelter, evacuate, or shelter with evacuation as a fallback plan) should be understood by occupants of each onsite building as part of an overall ERP. Toxic SIPs require an additional understanding of the time sequence associated with decision making and training so that the correct actions become second nature.

If outdoor personnel and occupants of other buildings are expected to enter the SIP in case of a toxic event, this should be addressed during training. By ensuring that personnel understand the general strategy of toxic mitigation, it is possible to attain the full safety benefit that the SIP is designed to provide. Lack of understanding the general approach for an SIP may result in repeated, unnecessary SIP barrier breaches. Insufficient training in this area may also result in personnel evacuating a perfectly safe environment into a highly lethal atmosphere.

The specific boundary of the SIP should be understood by all personnel who will shelter there. If the entire building is the SIP, this is not a significant issue, but if the SIP consists of one or more rooms within a building, it is imperative that occupants understand the primary and secondary SIP boundaries and ensure that they are closed and sealed to the extent practical. Occupants who don’t understand the SIP boundaries may shelter in unprotected parts of the building or may leave doors open or ventilation ducts unsealed, which would severely degrade the effectiveness of the SIP.

If a potentially lethal cloud of toxic gases impacts a “closed” building (no open louvers, doors, or windows), the indoor concentration will rise much more slowly than the outdoor concentration, and this ensures that time is available for occupants to respond accordingly. Toxic gas concentration in buildings with once-through ventilation systems and buildings with large openings such as some maintenance buildings, shops, and warehouses may become dangerous much more quickly.

The time afforded by a toxic SIP’s natural resistance to toxic impact allows highly effective mitigation strategies to be put into place if occupants are properly trained, and the necessary support equipment is present. Following is a list of response topics that should be communicated to personnel and fully understood by occupants of the SIP.

- The general approach (shelter, evacuate, or shelter with evacuation as a fallback plan) should be understood by occupants of each onsite building as part of an overall ERP. Toxic SIPs require an additional understanding of the time sequence associated with decision making and training so that the correct actions become second nature.

- If outdoor personnel and occupants of other buildings are expected to enter the SIP in case of a toxic event, this should be addressed during training. By ensuring that personnel understand the general strategy of toxic mitigation, it is possible to attain the full safety benefit that the SIP is designed to provide. Lack of understanding the general approach for an SIP may result in repeated, unnecessary SIP barrier breaches. Insufficient training in this area may also result in personnel evacuating a perfectly safe environment into a highly lethal atmosphere.

- The specific boundary of the SIP should be understood by all personnel who will shelter there. If the entire building is the SIP, this is not a significant issue, but if the SIP consists of one or more rooms within a building, it is imperative that
SIP occupants should be trained to implement the basic SIP immediate actions, even if they are normally performed automatically. One of the basic immediate actions is to either trip the HVAC system or switch it to 100% recycle mode (usually indicated by a big red button to ensure that this step is performed with high reliability). The other immediate action is to secure the primary and secondary boundaries of the SIP (pull doors closed and latch). As soon as immediate SIP actions are complete, secondary actions should be initiated.

SIP occupants should be aware of secondary actions that are to be taken to enhance SIP effectiveness and maximize the safety benefit the SIP affords. However, secondary actions should be clearly documented with clear directions that are specifically designed for the SIP. A standard approach is to provide an SIP kit with supplies such as duct tape and plastic, along with the response procedure. The response procedure should list the immediate actions, followed by all subsequent actions that are expected to be performed for the SIP.

Following is a list of subsequent actions that may be included in a typical SIP response procedure:

1. Seal ducts with plastic and duct tape (if leak-tight dampers are not installed). The procedure should include a diagram of the SIP along with each of the ducts to be sealed. It may be helpful to have pieces of plastic pre-cut to fit the ducts. Ensure that if access to the ducts requires a stepladder, one is available within the SIP boundary. A specially designed duct and cover combination such as metal and magnetic pair can enable occupants to quickly and efficiently seal the ducts.

2. Seal windows (if unsealed windows are present) with plastic and duct tape and the internal perimeter of the door with duct tape. Again, the location of the items to be sealed should be clearly shown to ensure that none are missed, and adequate supplies should be provided, keeping in mind that the door seal may be breached one or more times by people arriving at the SIP after it is sealed.

3. Initiate clean air flow into the SIP at the prescribed rate (if applicable). If the air supply system has flow or inventory monitoring capability, establish periodic readings to assist in contingency planning.

4. Document who is present and establish communications with emergency response personnel for accountability purposes.

5. Track toxic gas concentration within the SIP with respect to time. This will be used to assist with contingency planning. It would be helpful to provide writing utensils and a book with graph paper or empty tables to fill in to document toxic gas concentration (see Appendices for example forms for tracking SIP toxic gas concentration).

6. Review the actions to be taken as a fallback plan in case conditions degrade to that point. Identify what criteria will be used to determine when the SIP will be evacuated (indoor toxic gas reading higher than the pre-established threshold, for example). Explain that emergency response personnel will be contacted prior to evacuating the SIP and provide clear contact information. Communications with emergency response personnel ensures that decisions regarding evacuation are well-informed, and to identify the optimum evacuation route. Review the location and proper use of the escape packs or other PPE that may be used for evacuation.

SIP kits should contain the following:

1. Written SIP procedure.
2. A written list of the SIP contents (for replenishment purposes) for both the primary and secondary barriers, as applicable.
3. A diagram of the SIP Building showing the following:
   a. SIP primary boundaries
   b. SIP secondary boundaries (if applicable)
   c. Location of any doors, windows, and vents within these boundaries that are to be sealed
   d. The location of the SIP kit and ladder, if applicable

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### Figure 7-1. Mitigation of Primary Leak Points of an Interior Shelter Room

<table>
<thead>
<tr>
<th><strong>Windows</strong></th>
<th><strong>Doors</strong></th>
<th><strong>Walls</strong></th>
<th><strong>Ventilation</strong></th>
<th><strong>Floor / Roof</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Properly sealed, if present</td>
<td>Properly fitted to the frame</td>
<td>Full contact with floor and next floor / roof or finished ceiling (not terminated slightly above a drop ceiling)</td>
<td>Leak-tight damper on each path into and out of SIP room</td>
<td>Leak-tight barrier with all penetrations sealed leak-tight</td>
</tr>
<tr>
<td>Non-functional (cannot be opened)</td>
<td>Equipped with functional latches</td>
<td>All penetrations sealed</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Materials for sealing openings</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>a. 2-inch wide duct tape</td>
</tr>
<tr>
<td>b. Plastic sheeting of sufficient quantity to cover all openings that are identified to be sealed</td>
</tr>
<tr>
<td>c. Scissors for cutting plastic sheeting and duct tape</td>
</tr>
<tr>
<td>d. Stepladder(s) of suitable height (if applicable)</td>
</tr>
<tr>
<td>e. The location of the HVAC shut-down controls</td>
</tr>
<tr>
<td>f. Directions (i.e., an arrow pointing north) to accommodate communications with ERP</td>
</tr>
</tbody>
</table>

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8 Fallback Plan

To establish a highly effective fallback (evacuation) plan, the SIP should have each of the following elements:

✽ Reliable indoor toxic gas concentration monitoring
✽ Procedures that identify criteria for implementing the fallback plan
1.Evacuation criteria are typically a set of toxic gas concentration thresholds for each applicable toxin.
2. Direction should be provided to contact emergency response personnel prior to evacuating the SIP.
✽ Trained personnel to ensure that appropriate actions are understood and taken
✽ Communication channel between the SIP and emergency response personnel:
1. Emergency response personnel should be provided real-time toxic gas concentration readings and weather data to allow the toxic threat to be understood and to enable optimum evacuation routes and safe muster points to be identified.
2. Emergency response personnel who will communicate with SIP occupants should be trained in SIP operations and fallback procedures to ensure that they provide guidance consistent with the toxic emergency plan.
3. Note that for a large facility (e.g., refinery) with dozens of potential SIP buildings, some may be upwind of the toxic release and others downwind, so any emergency response personnel providing evacuation guidance need to do so carefully with respect to specific SIP buildings, wind directions, and the toxic release location and type. Ultimately, the decision to evacuate should be made by the SIP building occupants and communicated to the emergency response team.
✽ Reliable, appropriate escape packs in sufficient quantity for the peak number of personnel expected to shelter in the SIP to allow their safe evacuation, if necessary. Examples include:
1. In the event of an evacuation involving HF, additional full body PPE may be required in addition to fresh air.
2. For evacuations involving some common toxins, manufacturers have developed filter escape packs (non-air supplied) that are highly effective if the outdoor toxic concentration is at or below their filter breakthrough concentrations.

9 Measuring SIP Effectiveness

Knowing how effective an SIP is at mitigating risk allows resources to be optimized in minimizing risk to the extent practical. For example, the importance of an effective fallback plan depends on the following parameters:

✽ HVAC ingestion rate
✽ Reliability and timeliness of HVAC isolation
✽ Leak tightness (infiltration rate with HVAC isolated)
✽ Timeliness of implementing additional mitigation measures (i.e., sealing the SIP room)
✽ HVAC egress rate
✽ Leak tightness of sealed SIP room
✽ Likelihood of a toxic plume impacting the SIP
✽ Potential intensity of the toxic plume that may impact the SIP
✽ Duration of the toxic plume

By evaluating these parameters, the toxic risk can be quantified, and the safety benefits of potential mitigation strategies can be determined.

Common SIP leak tightness testing methods are blower door and tracer gas tests. One advantage of blower door testing (see Figure 9-1) is that it can be done in any weather condition because differential pressures established during the test are significantly higher than those caused by wind. It also provides infiltration rates as a function of differential pressure, instead of a single point. An advantage of the tracer gas test is that it measures the parameter of interest (amount of air exchange per unit time) for a condition that is representative of actual accident conditions (wind-driven differential pressures). However, without data for a range of wind speeds, the data must be extrapolated using theoretical correlations to estimate infiltration rates for other conditions. Example results of tracer gas testing are shown in Figure 9-2.

Figure 9-1. Blower Door Test Setup

Figure 9-2. Tracer Gas Test Sample Results
10 References

1. Premier Safety: https://www.premiersafety.com/respiratory/supplied-air/cascade-breathing-air-assemblies

11 Key Terms

- **Infiltration** - Air leaking into the building once the HVAC system is isolated.
- **Ingression** - Air being actively drawn into the SIP by the HVAC system.
- **Emergency Response Plan** - A documented procedure of steps to follow during an emergency, here it is specific to toxic gas release.
- **Shelter In Place** - Mechanism to shelter in a building during a toxic gas release event.
- **Flammable Gases** - A flammable gas is a gas that burns in the presence of an oxidant when provided with a source of ignition. Flammable gases can include methane, acetylene, ammonia, hydrogen, propane, propylene and others [Ref. 8]
- **HVAC** - Heating Ventilation and Air Conditioning system for a building, for toxic shelter in this document.
- **Risk Tolerance Criteria** - Tolerable risk as determined by the owner/operator of the facility where the toxic release could occur.
- **Leak-tight SIP Building** - A toxic SIP building with minimal infiltration rate thereby reducing the potential toxic dosage inside building and reducing occupant vulnerability.
- **Occupant Vulnerability** - Probability of death of personnel inside the shelter due to impact from toxic gas released at the facility.
- **CO2 Buildup** - Buildup of CO2 inside the toxic shelter building due to inhabitants without being able to have adequate air exchange.
- **O2 Depletion** - Reduction in the oxygen content in the shelter due to buildup of CO2 (see CO2 buildup).
- **Toxic Gas Monitors** - Gas detectors that are designed to monitor concentrations and generate a signal or an alarm when a certain threshold value is breached. These monitors are specific to the type of toxic gas.
- **Primary SIP Barrier (also referred to as Building Envelope)** - Toxic shelter building where occupants can go to reduce exposure to toxic gases.
- **Secondary SIP Barrier** - Internal SIP room in the toxic shelter.
- **Leak Tight Dampers** - Air dampers that are designed leak tight to prevent toxic gases from entering the toxic shelter.
- **SCBA** - Self Contained Breathing Apparatus worn by inhabitants of toxic shelter while evacuating the building.
- **PPE** - Personal Protective Equipment worn by inhabitants of toxic shelter while evacuating the building (SCBA, Positive Pressure Suits, etc).
- **Blower Door Testing** - One of the testing mechanisms used to test leak tightness of a building using blower door and pressure gages.
- **Tracer Gas Testing** - One of the testing mechanisms used to test leak tightness of a building using tracer gases and monitoring the decay of those gases over time.
# 12 Sample SIP Gas Tracking

## SIP Concentration Tracking Table

<table>
<thead>
<tr>
<th>Time (hh:mm)</th>
<th>Time elapsed (minutes)</th>
<th>SIP Room Concentration (ppm)</th>
<th>Building monitor 1 concentration (ppm)</th>
<th>Building monitor 2 concentration (ppm)</th>
<th>HVAC Inlet Concentration (ppm)</th>
</tr>
</thead>
<tbody>
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## Concentrations of Interest

<table>
<thead>
<tr>
<th>Toxin</th>
<th>Concentration (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prepare to evacuate</td>
<td>300 ppm</td>
</tr>
<tr>
<td>Evacuate</td>
<td>500 ppm</td>
</tr>
<tr>
<td>Potentially lethal</td>
<td>1,000 ppm</td>
</tr>
</tbody>
</table>

*Figure 12-1. Sample SIP Gas Concentration Tracking Table*

## Gas Concentration Tracking Graph

- **1,000 ppm** - Potentially lethal concentration
- **500 ppm** - Initiate fallback plan (evacuate)
- **300 ppm** - Contact ER to discuss fallback plan (evacuation)

*Figure 12-2. Sample Gas Concentration Tracking Graph*
Our Experts

Anthony Sarrack is a Principal Risk Analyst and the technical lead for toxic shelter design and testing. He previously worked in the nuclear power and weapons reactor industry and has worked for BakerRisk since May 2006. In that time, he has been instrumental in the development of Facility Siting Study and Quantitative Risk Assessment methodology and documentation as well as toxic shelter assessments and testing methodology.

Murtaza Gandhi works in the Process Safety Group. He is an Electrical Controls Engineer with 14 years of experience in controls and safety systems, and 7+ years experience in qualitative hazard analysis. He has extensive experience with various phases of the safety life cycle including SIL assignment, SIL calculation, SIL facilitation and verification, FAT, SAT, and startups. He has been a continuous member and leader of ISA at the student, local, and national level since 2001.

Karen Vilas is the Supervisor of Business Development and Marketing. In addition, Karen is a Principal Consultant in the Process Safety Group specializing in Consequence and Risk Modeling as well as Insurance Risk Engineering. Karen has worked extensively with clients in the refining and petrochemical industries with a focus on risk quantification and mitigation of blast, toxic, flammable and fire hazards. In addition to servicing clients’ process safety needs, Karen oversees the Business Development and Marketing group, focusing on industry education of key risk management topics through conference technical content coordination and media content development.

As a Senior Principal Consultant and Director of Process Safety, Bill Mather has provided a wide variety of process safety and risk engineering services to oil, gas, chemical, and petrochemical companies around the world. Bill works on projects including risk management services for LNG liquefaction facilities and regasification terminals; liquid and gas transportation pipeline systems; offshore well and processing platforms, FPSOs; siting studies for refineries and chemical plants, and QRAs for major oil and gas operations worldwide.
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