Shelter-In-Place

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Sheltering Topics

- Shelter strategies
- Infiltration rates & protection factors
  - Houses
  - Buildings
  - Automobiles
- Shelter Effectiveness
- Public Compliance

Assumptions

- Evacuation is the preferred protective action when it can be completed before the toxic plume arrives.
- Shelter-in-place may be preferable if there is not enough time to evacuate. Example populations include:
  - People very close to the hazard source
  - Mobility-impaired individuals
  - Institutional populations (e.g., hospitals, schools, nursing homes)

Protective Action Decision-Making

- To decide between evacuation and shelter-in-place, local planners and decision makers must consider various aspects of
  - Release characteristics (type and quantity of chemical, duration, release mode--spill, fire, or detonation)
  - Meteorological conditions (wind speed and direction, estimate plume travel time and strength)
  - Population characteristics (location, mobility-impaired, transportation disadvantaged)
  - Evacuation network characteristics (capacity, speed)
  - Shelter characteristics (infiltration rates)

Types of Shelter-in-place

There are 4 types of shelter-in-place defined in CSEPP:

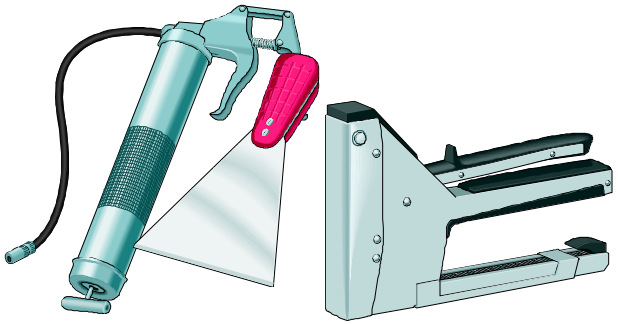
- Normal
- Enhanced
- Expedient
- Pressurized

Normal Shelter-in-place

- **Normal** shelter-in-place: nothing has been done to modify the house or building except closing the windows and doors, and shutting off the heating or air system and fans. No normal building is completely air tight, so eventually the chemical agent is likely to seep in.

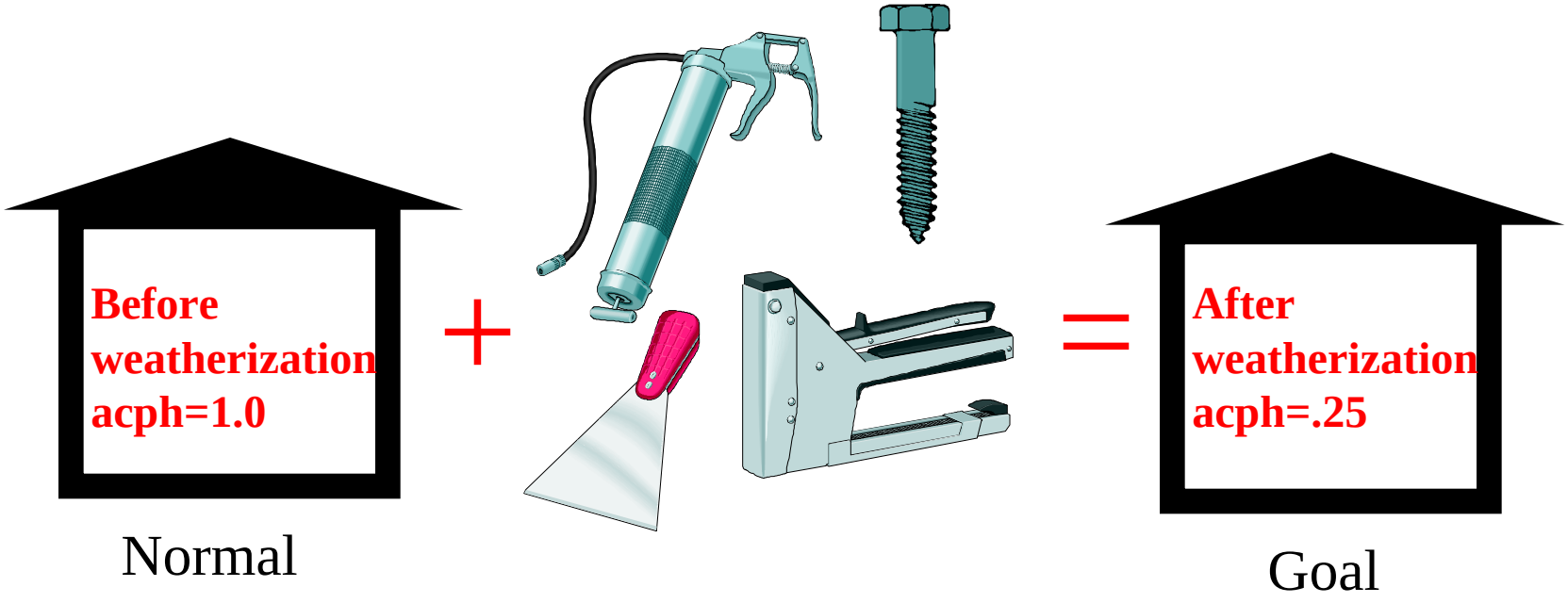
Enhanced Shelter-in-place

- **Enhanced** shelter-in-place: weatherization techniques are applied to the house or building before the emergency to permanently reduce the rate at which air or chemical agent seeps into the structure.
- Example weatherization techniques include:
  - weather-stripping or caulking doors, windows and attic hatches
  - replacing broken window panes
  - closing off fireplaces, etc.



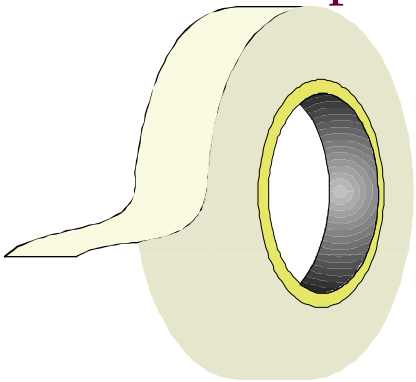
Enhanced Shelter-in-place

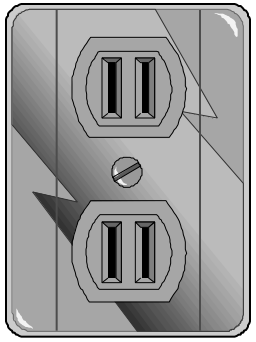
- A goal of enhanced shelter-in-place could be to lower the infiltration rate to 0.25 acph.

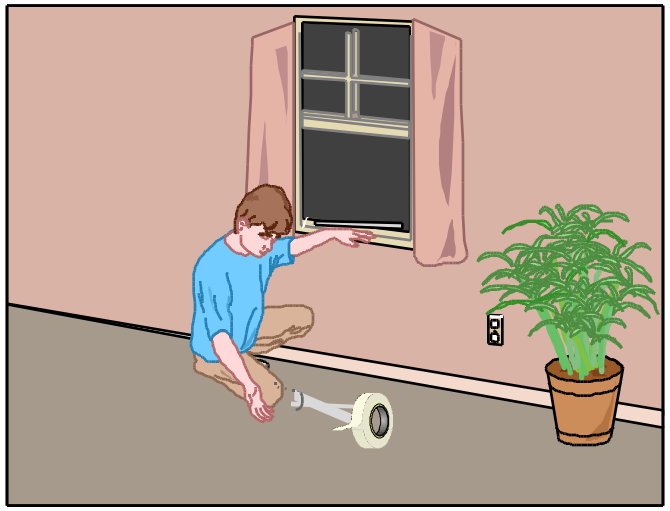


Expedient Shelter-in-place

- **Expedient** shelter-in-place: measures are taken at the time of an emergency to reduce the rate at which air enters into the room selected for use as an expedient shelter. Emergency measures would likely include taping around doors and windows, and covering vents and electrical outlets with plastic sheeting.







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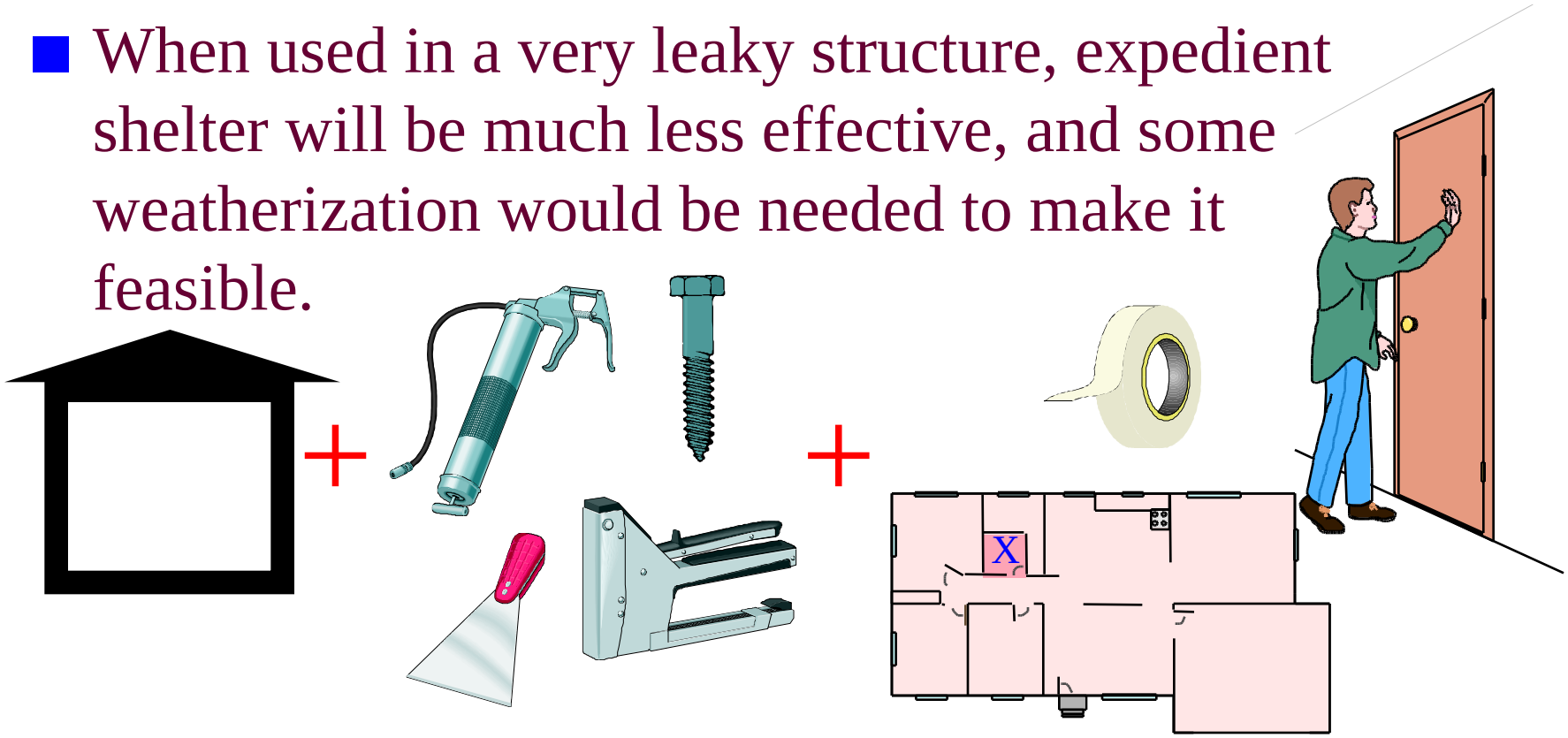
Combining Enhanced and Expedient Measures

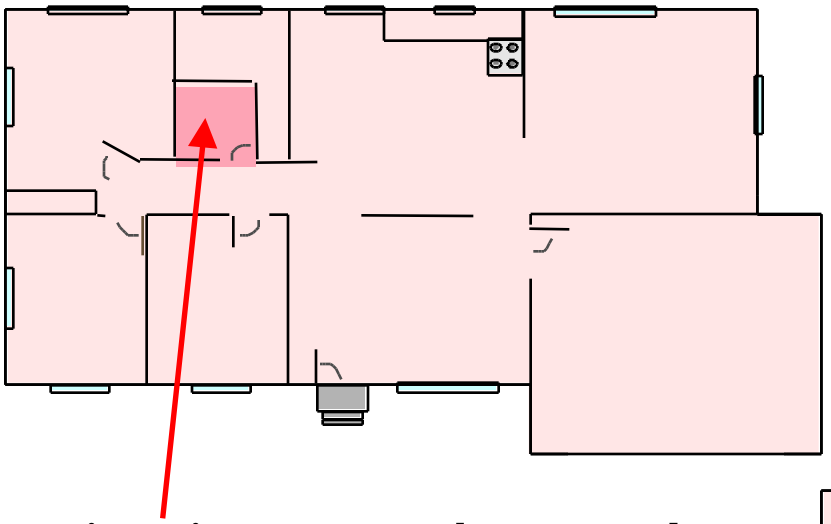
- When used in a very leaky structure, expedient shelter will be much less effective, and some weatherization would be needed to make it feasible.



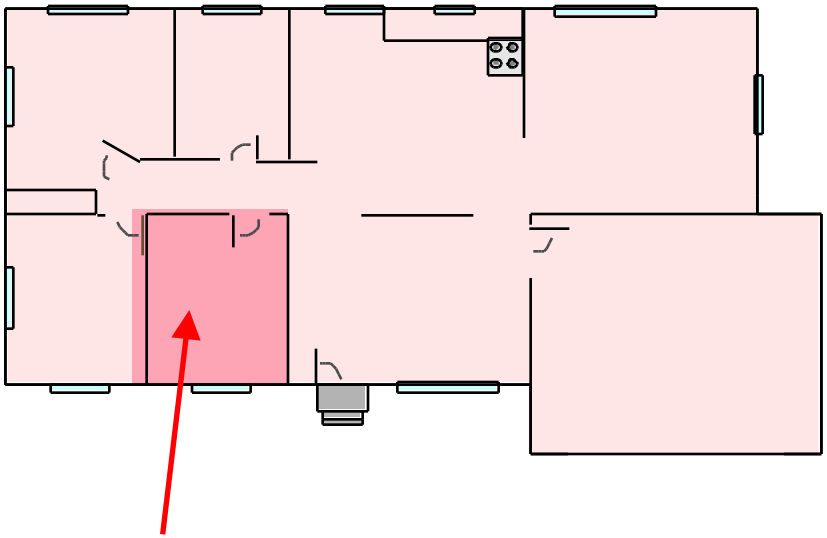
Enhanced

Expedient

Combining Enhanced and Expedient Shelter-in-place Measures



An **interior room** with no outside walls chosen for expedient shelter-in-place. Air exchange is primarily with the air inside the structure. Expedient measures are likely to substantially reduce infiltration rate of outside air into the interior room.



An **exterior room** with an outside wall chosen for expedient shelter-in-place. Air exchange is with both inside and outside air. Additional protection provided is lower than for an inside room.

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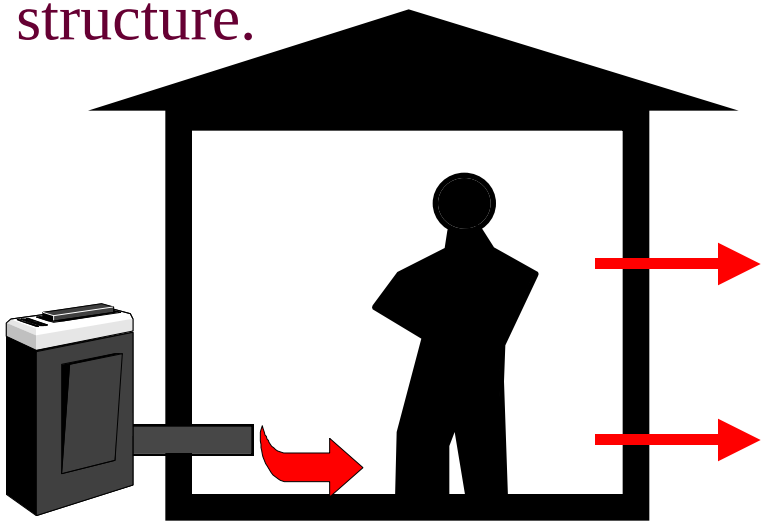
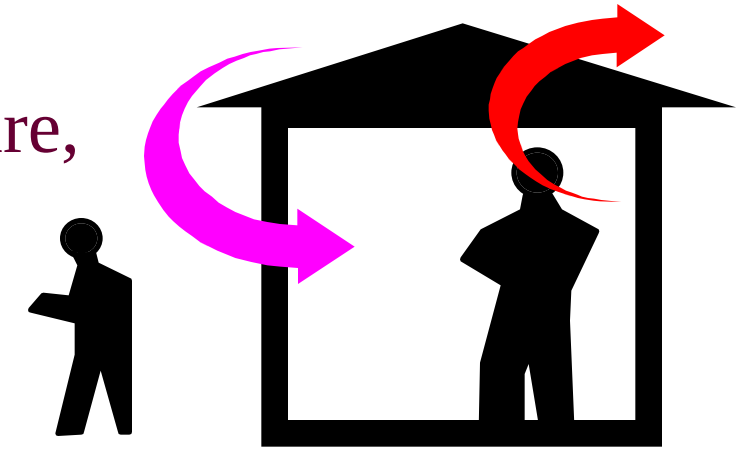
Pressurized Shelter-in-place

Pressurized shelter-in-place: outside air is drawn into the shelter through a special filter that removes the chemical agent. This filtered air creates a positive pressure in the shelter so that clean air is leaking out instead of contaminated air leaking in. This method eliminates the infiltration of outside air or chemical into the structure.



Infiltration

- Air inside a building is constantly being replaced with air from outside, especially around windows, doors, building seams, pipes, electrical fixtures, and heating or cooling ducts, due to infiltration.
- The degree of protection a shelter provides depends on how leaky it is, which is measured by its infiltration rate.
- Influenced by air temperature, air pressure, wind speed, and vegetation.



Infiltration Rate

- Infiltration rate is measured in air changes per hour (acph).
- Does not mean that all air will be replace in that period of time because of mixing.
- Wilson estimates:
  - 63% of the air will be exchanged in 1h x 1/acph
  - 95% of the air will be exchanged in 3h x 1/acph

Air Replacement Times

	acph			
	.25	.50	1.0	2.0
63%	4h	2h	1h	.5h
95%	12h	6h	3h	1.5h

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Infiltration Rates in U.S. Housing Stock

- Varies from 0.2 acph to approx. 5.0 acph (assume heating and air conditioning systems off.)
- Older homes in rural South (unweatherized) often have infiltration rates of approx. 4.0 or 5.0 acph.
- Weatherized, modern house incorporating energy conservation features usually has infiltration rate of approx. 0.2 to 0.5 acph.
- The average U.S. house is about 0.7 acph. A “tight” house is considered to have an infiltration rate < 0.5 acph.
- Taping and sealing a room (“expedient” shelter-in-place) inside an average home results in an infiltration rate of 0.1 to 0.6 acph (mean of 0.3 acph) in the sealed room.

Variations in Infiltration

- Linear increase with wind speed
- Increase with temperature difference between outside and inside (square root of difference)
- Lower with vegetation surrounding buildings
- Higher for single-story buildings than for two-story buildings

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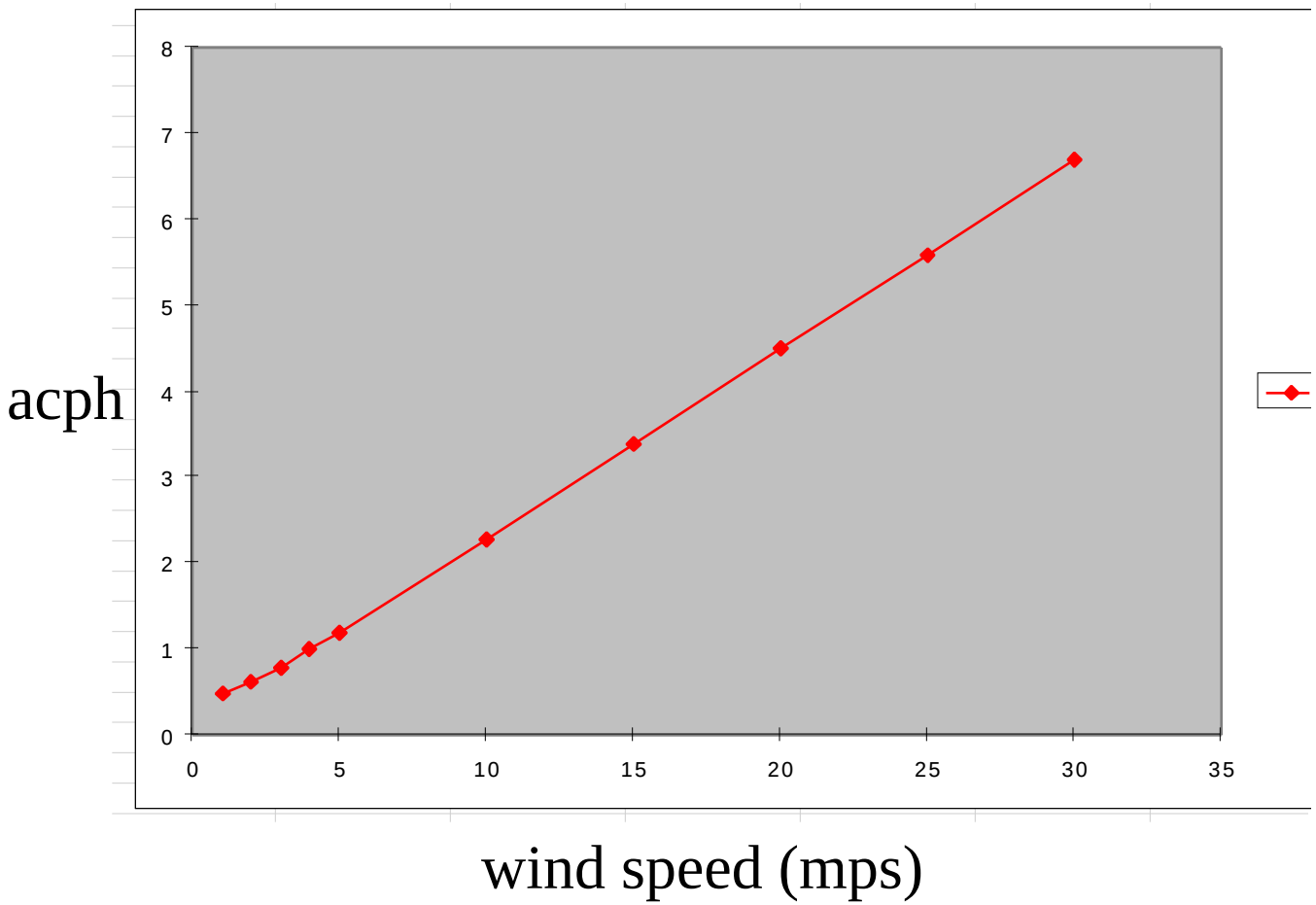
Infiltration in ALOHA Varies With Temperature and Windspeed



Variability in Infiltration

- Wilson's work showed air exchange in a single house varied from 0.1 and 0.5 over a month of measurements.

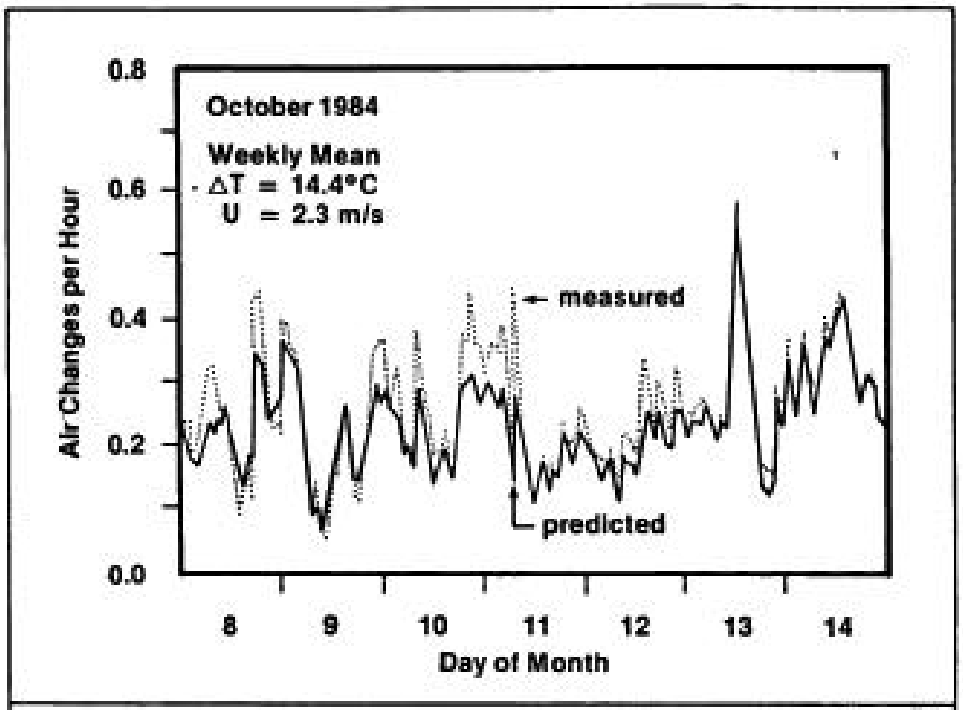


Figure 2: Measured and predicted outside air infiltration rates in a test house in Edmonton. From Yuill et al. and Wilson (1985)

Office/Commercial Buildings

- Little data exists
  - One study showed infiltration varied between 0.2 and 0.7 achp
- Estimated to be lower than residential structures
  - 0.66 acph for office buildings
  - 0.31 acph for industrial buildings

Automobile Infiltration

- 1975 Study
  - Stationary idling: 18 acph ac on; 24 ac off
  - Moving, air on: 18–38 acph at 0 to 55 mph
- 1991 study
  - Stationary off: 0.5 acph
  - Stationary, ac fan on: 2.5 acph
- 1994 study
  - Moving, 35 mph: 15 acph
  - Moving, 70 mph: 40 achp

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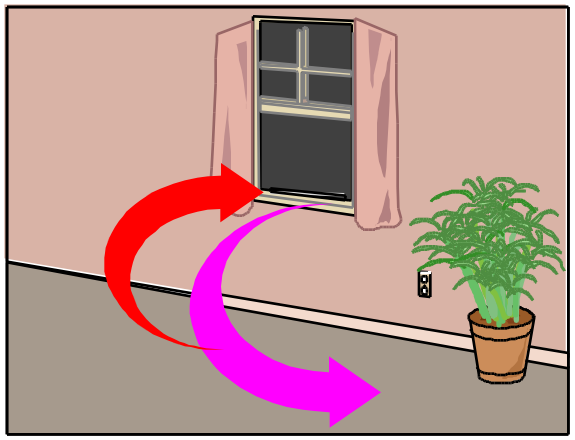
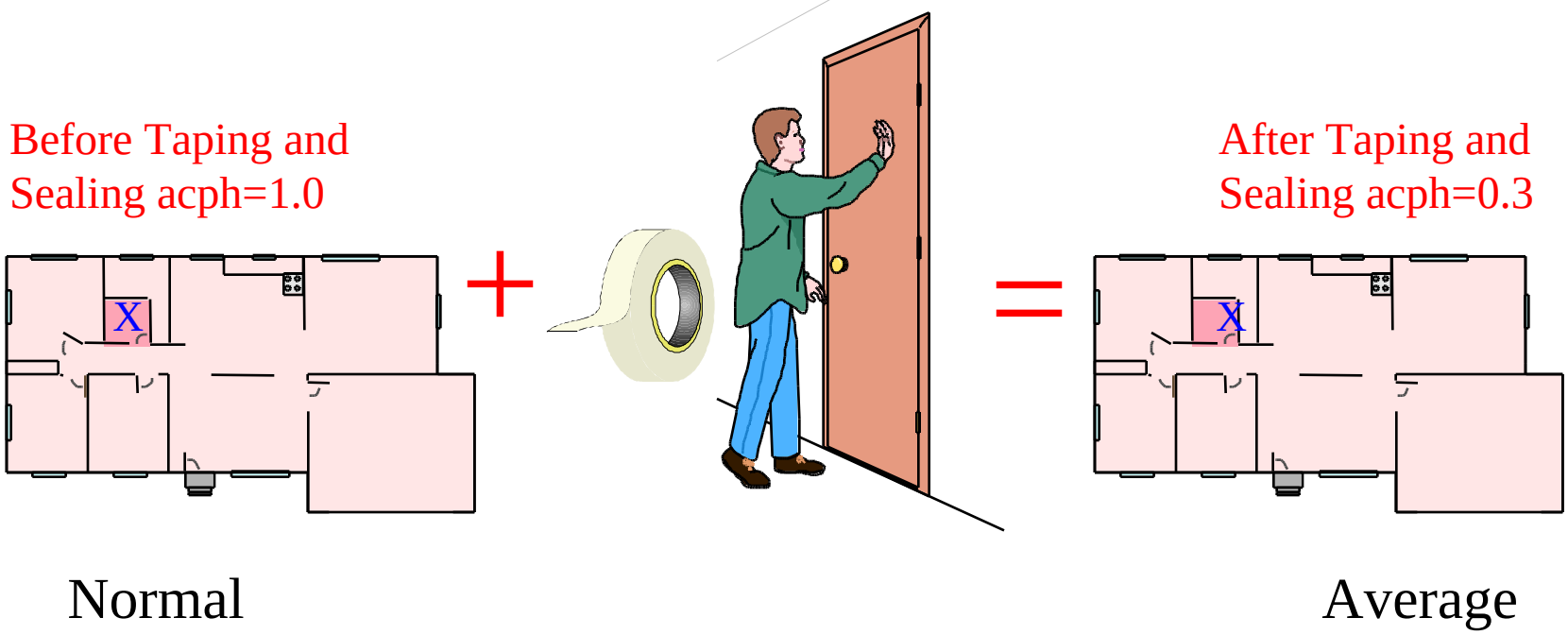
Expedient Shelter-In-Place Infiltration Rates

- Air is exchanged between room and other indoor areas in the structure
- Air is exchanged between room and outdoors
- Effectiveness influenced by relative portion
- Little is known about this type of exchange



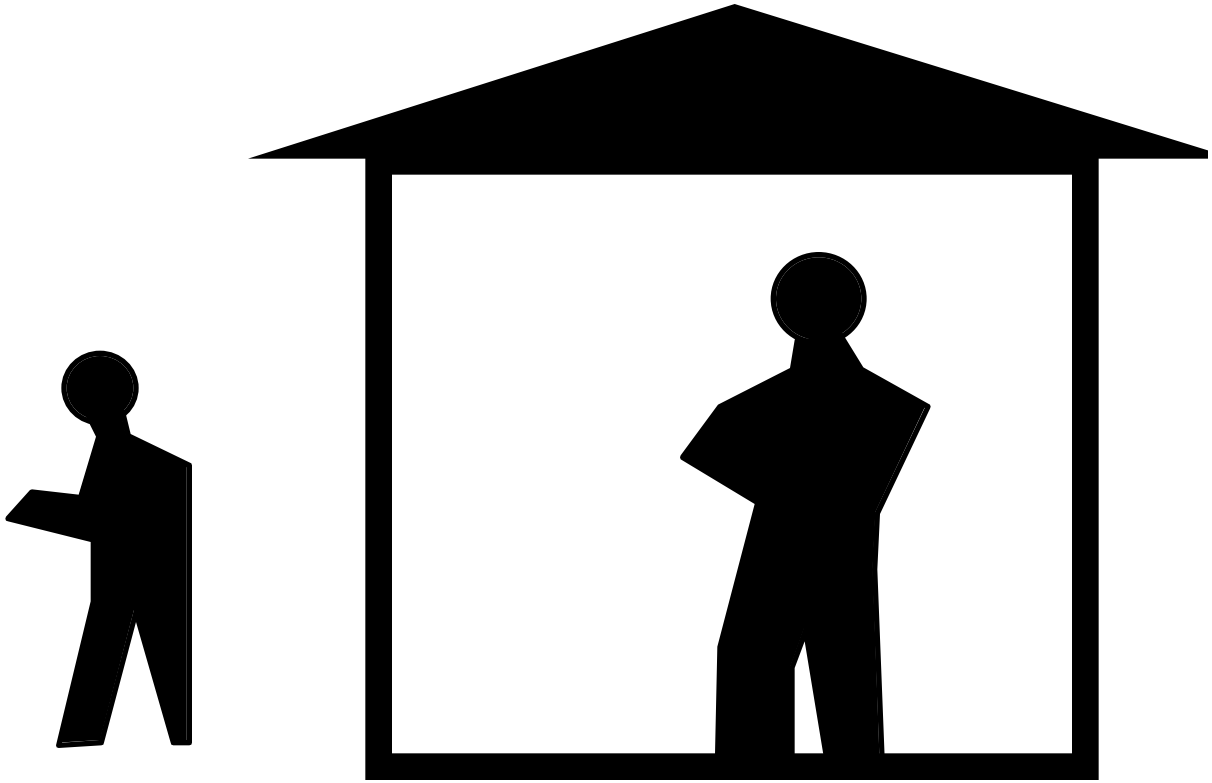
Expedient Shelter-in-place

- One study showed in a limited number of trials that the infiltration rate for rooms used as expedient shelter ranged from about 0.1 to 0.6 acph, with an average of 0.3 acph.



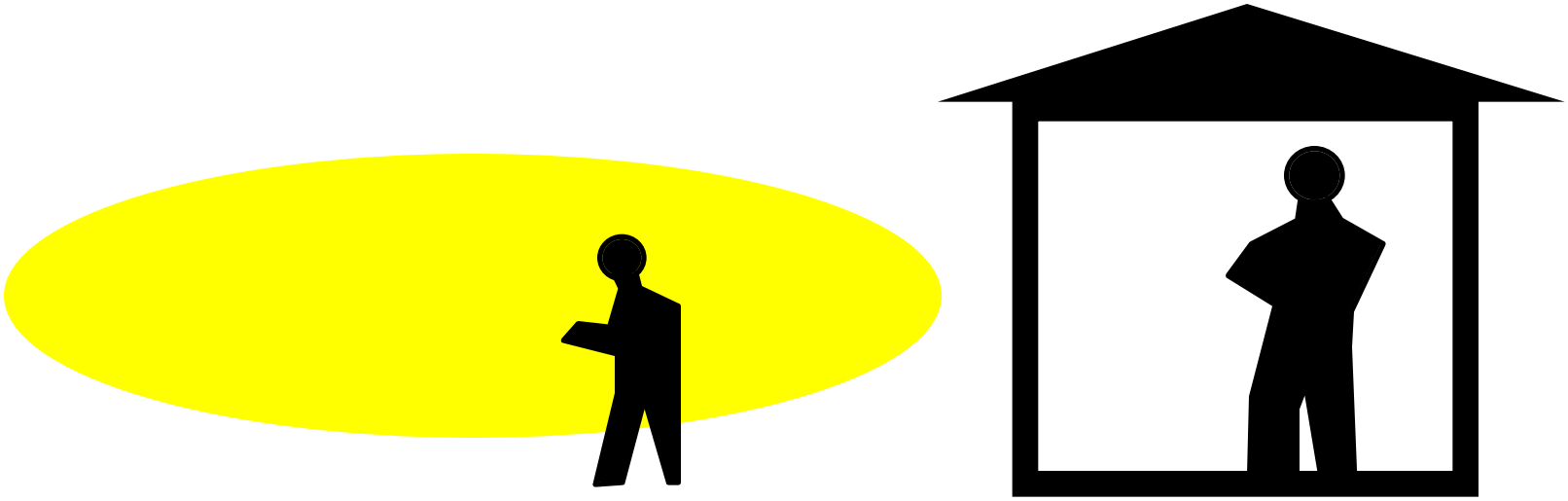
Characterizing the Process

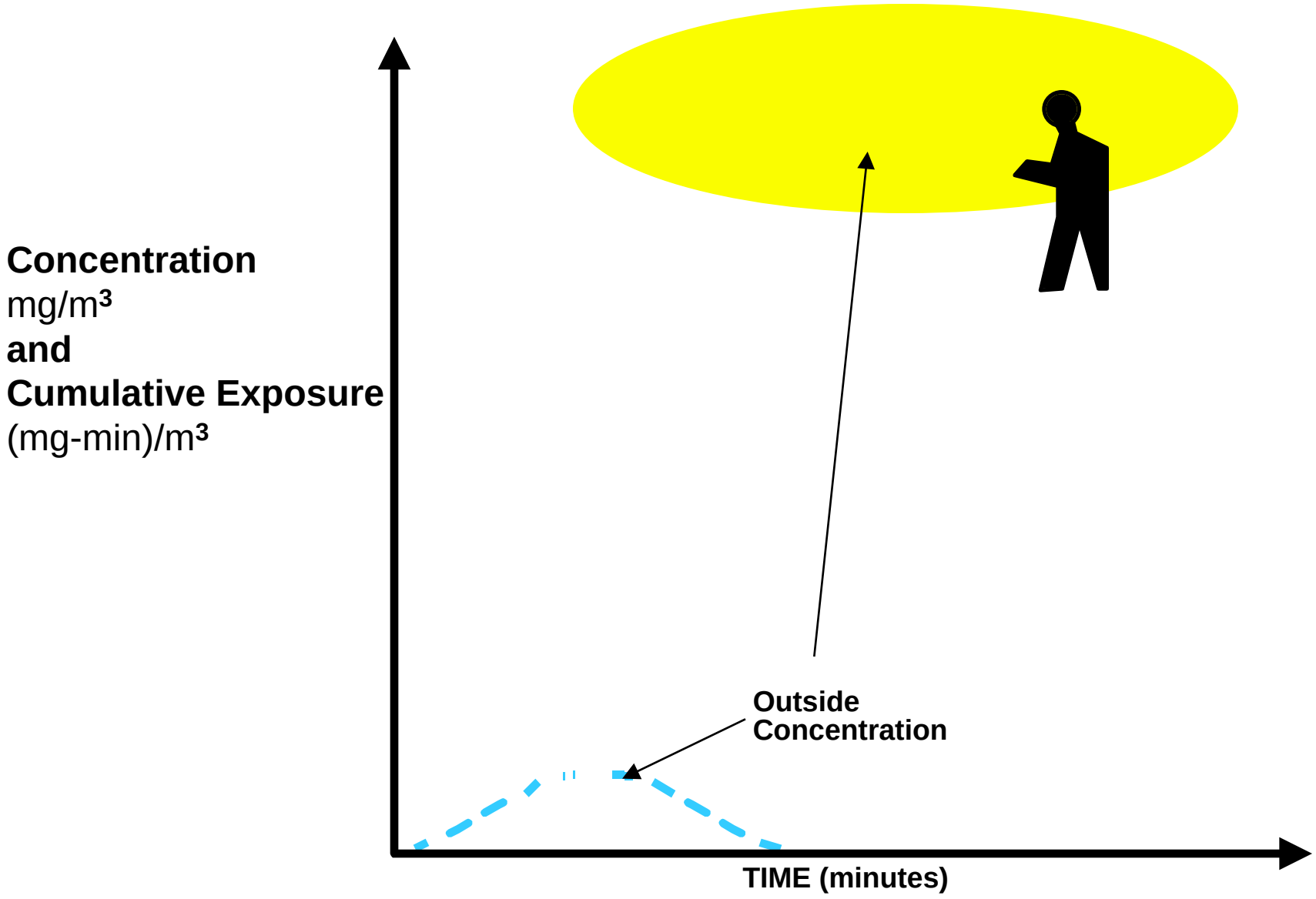
- Before the plume arrives there is no chemical inside the unpressurized shelter.



After Release

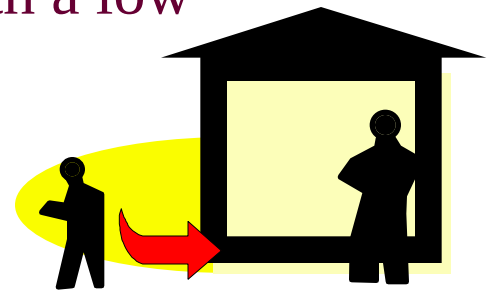
- Following a vapor release of chemical, a plume containing a concentration of chemical travels downwind toward an unpressurized shelter.



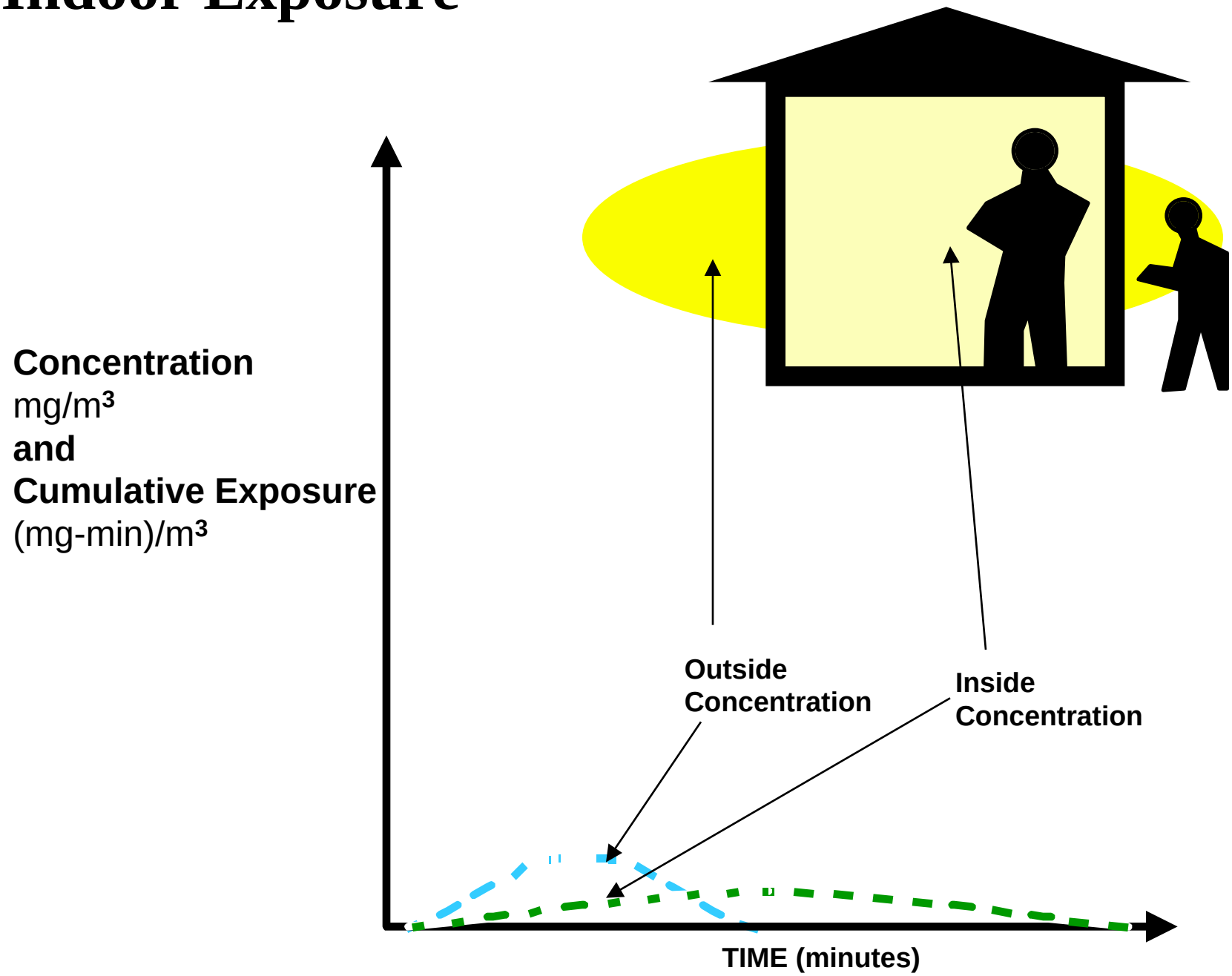

Concentration
mg/m³
and
Cumulative Exposure
(mg-min)/m³
Outside
Concentration
TIME (minutes)

Infiltration

- The chemical plume continues to move and passes around the unpressurized shelter. As the concentration of chemical outside changes, the concentration of chemical inside would change as well.
- If the outside air contains chemical vapors, then chemical enters the unpressurized shelter as the air from outside replaces the air inside the shelter due to infiltration.
- With a high infiltration rate the concentration inside would rise more rapidly than in a similar house with a low infiltration rate.

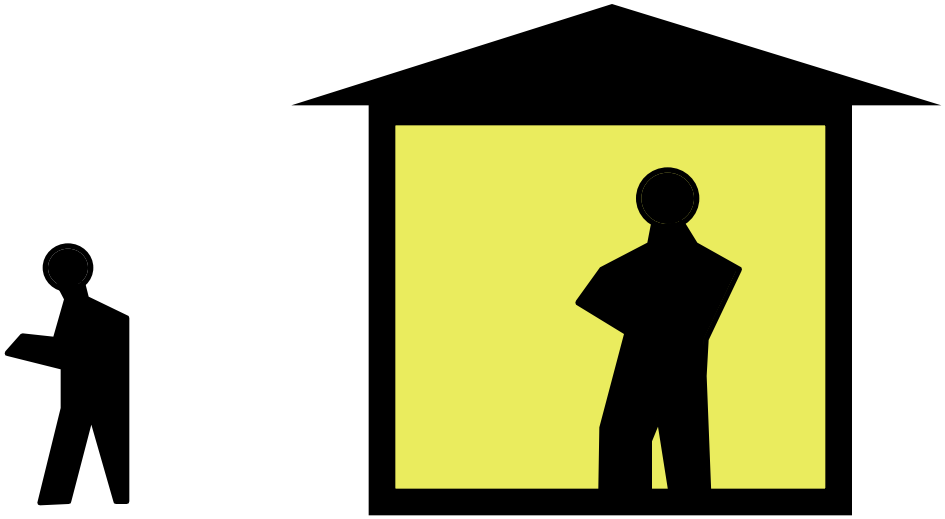


Indoor Exposure

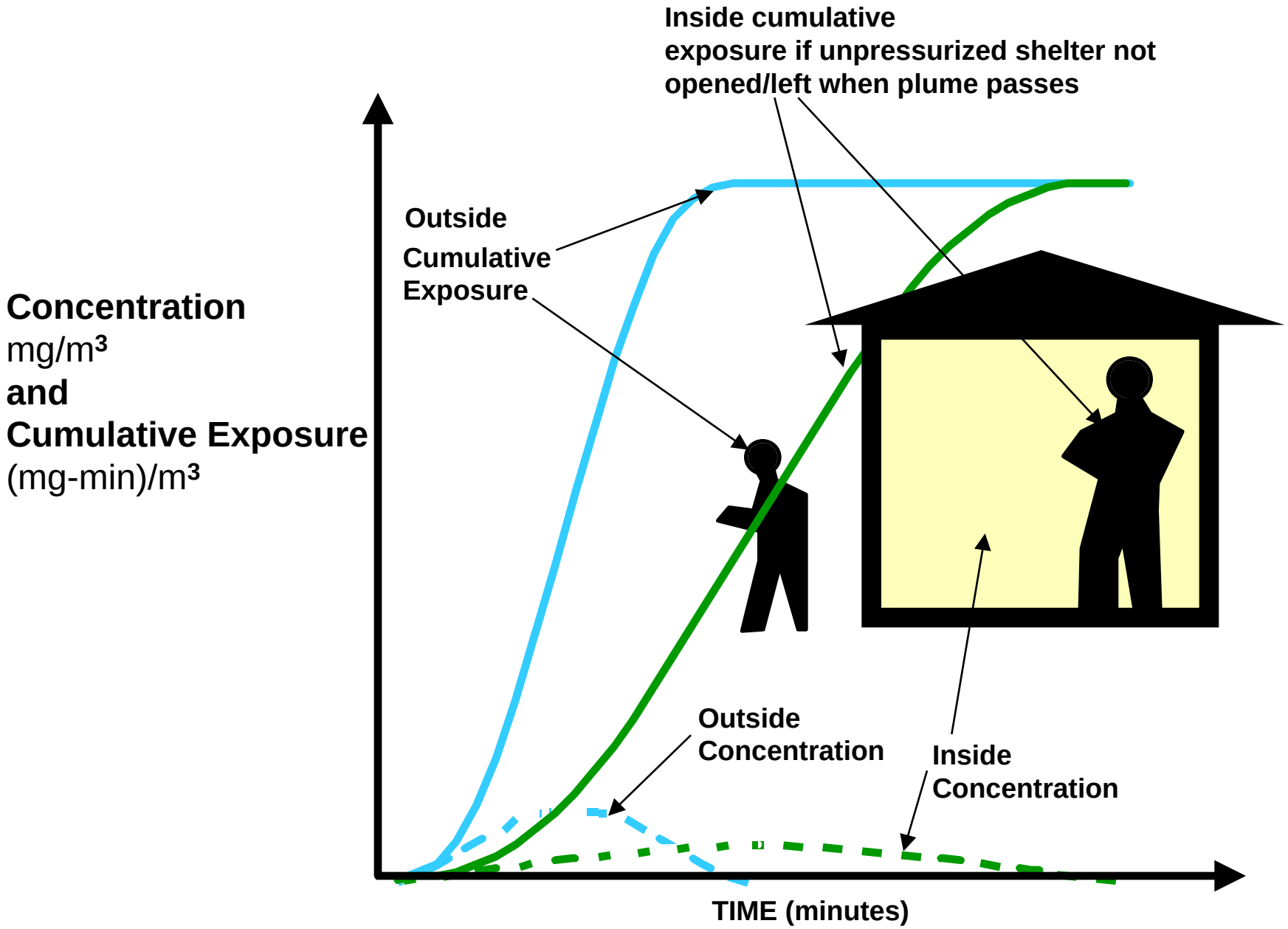


Plume Passage

- After the chemical plume has passed the unpressurized shelter, the air outside contains no chemical, but the air inside the shelter will contain chemical which entered while the plume was present.



Overall Equation



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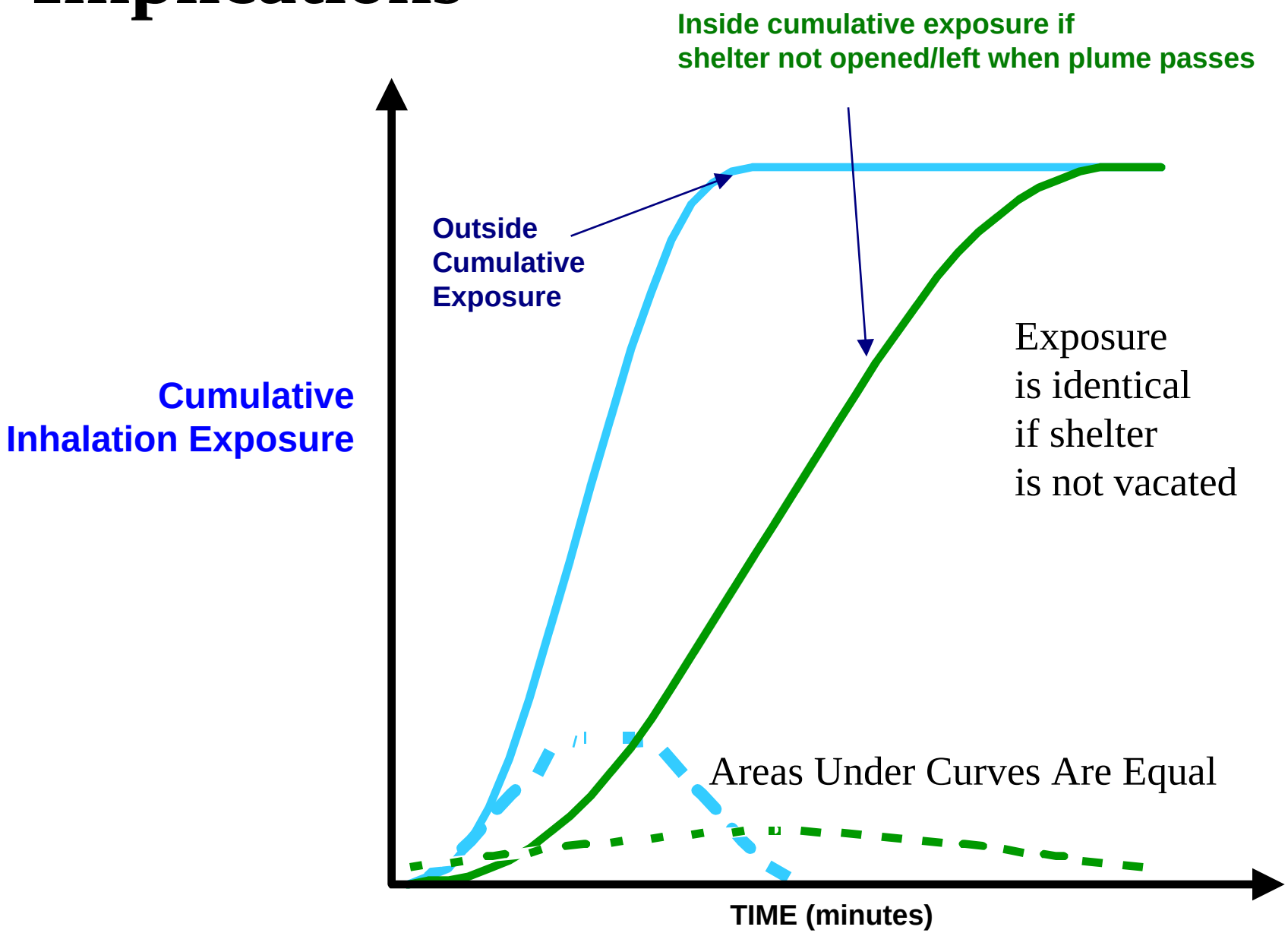
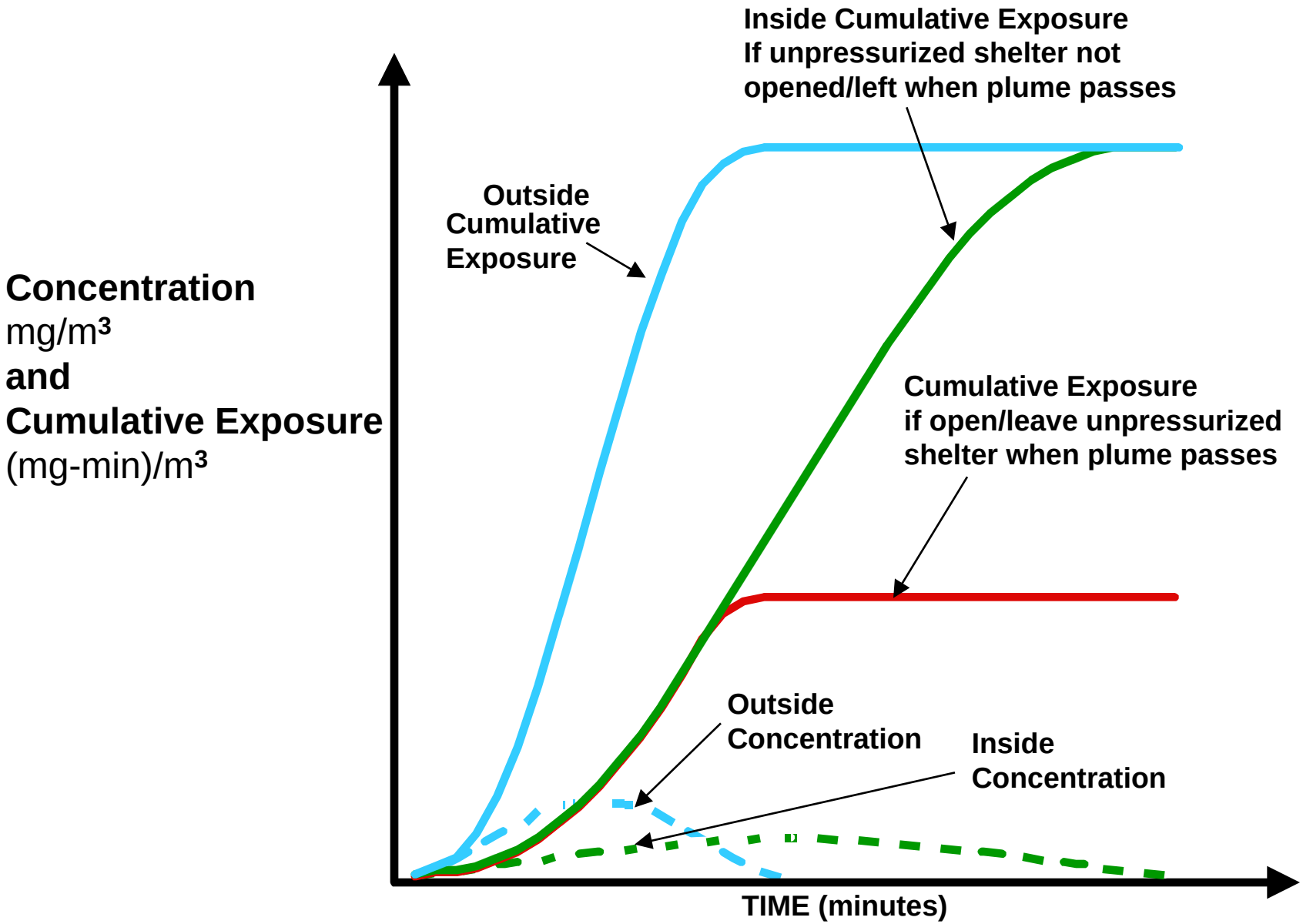
Implications



Need to vacate shelter



What Can Happen If Sheltering Is Implemented After Plume Arrival

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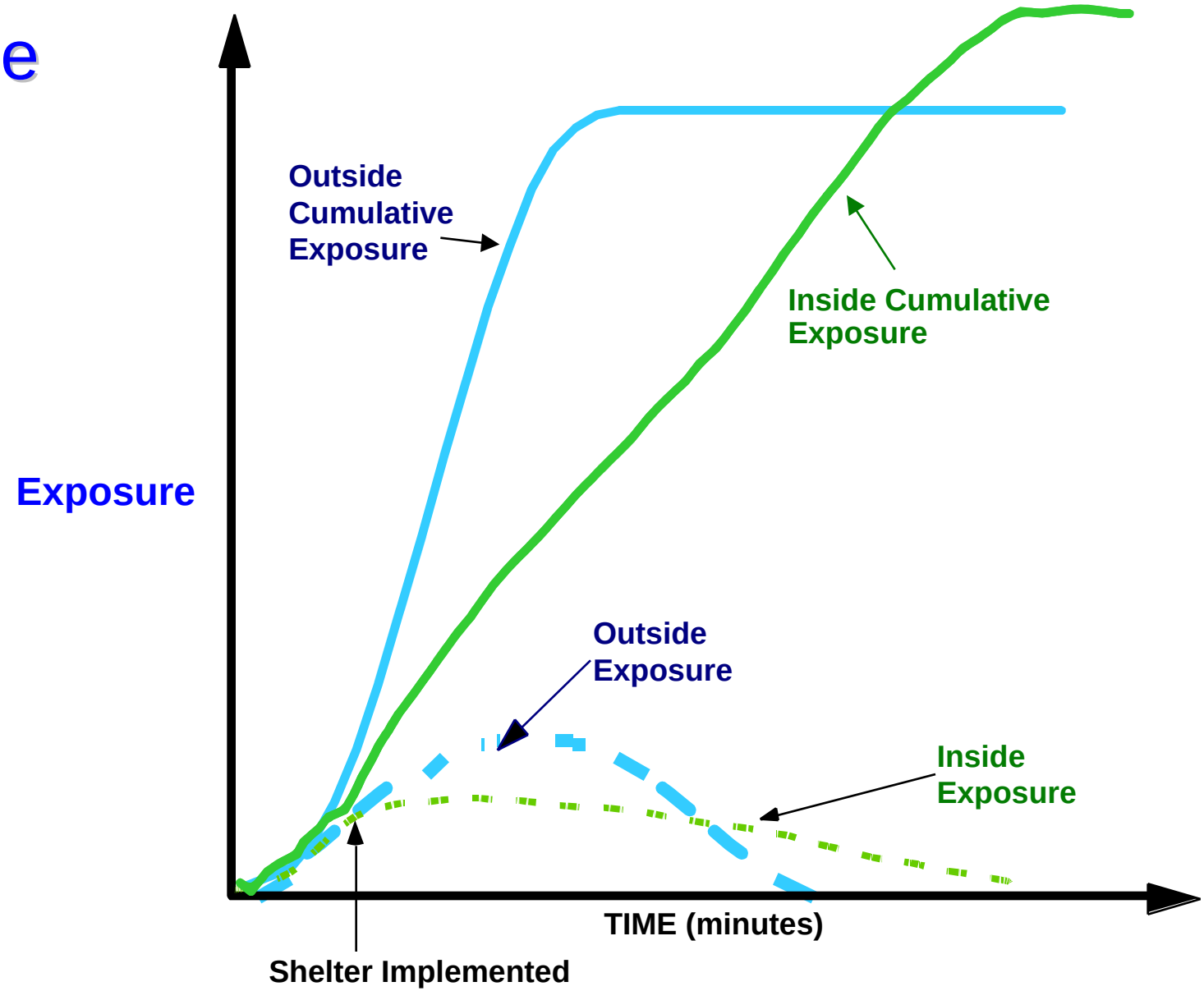
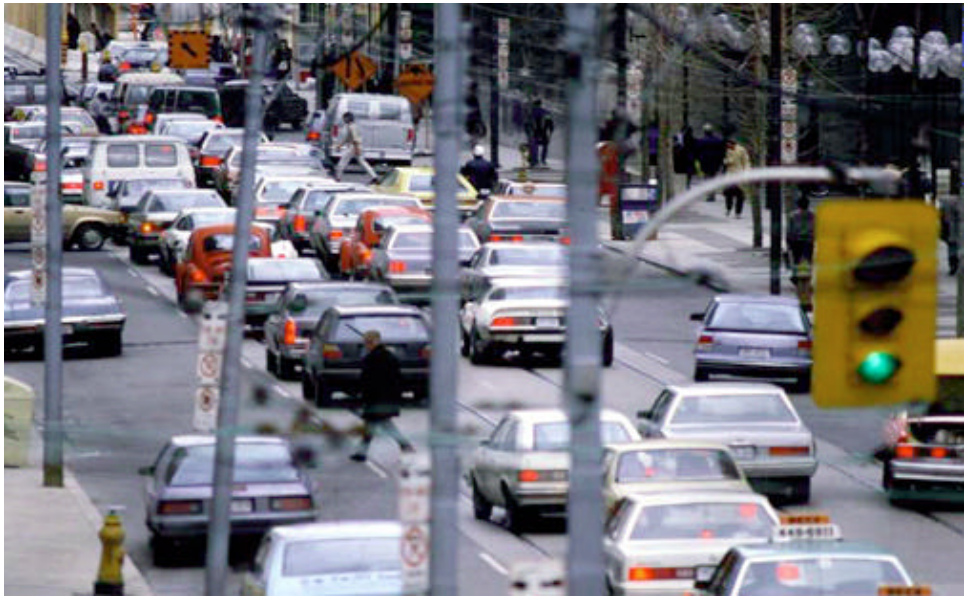


Leaving or Opening the Unpressurized Shelter

- If people remain in the closed, unpressurized shelter without the addition of fresh air, they will continue to be exposed to any chemical remaining in the unpressurized shelter.
- If people leave the unpressurized shelter at an appropriate time after the plume has passed, then they will not be exposed to any more chemical via inhalation.
- Another option is to open the shelter and ventilate to “flush” air containing chemical out of the unpressurized shelter.
- In some cases, people may still need to wait inside the opened shelter until the authorities determine that it is ok to exit the area.

Will People Shelter?



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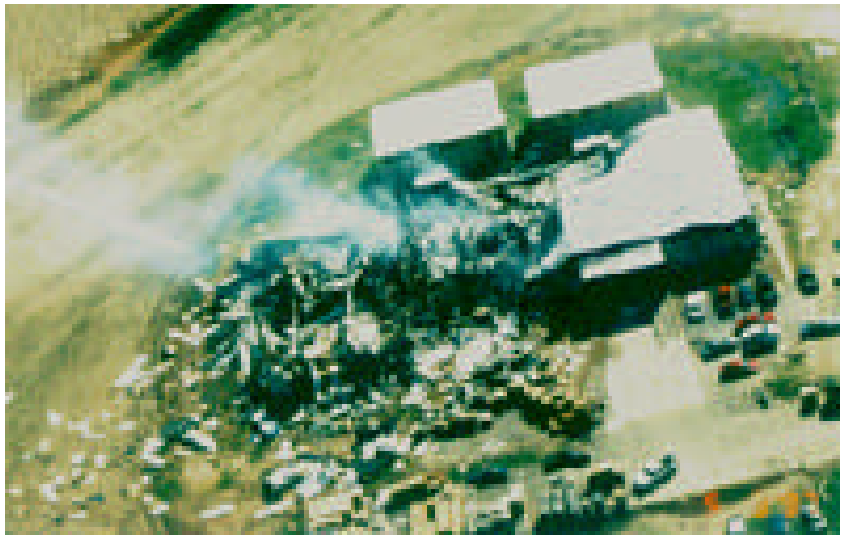
View of Site in West Helena, AR



Background

- Demographics
  - 17,910 in West Helena and Helena (AR)
  - 43% live below poverty (AR average 16%)
  - 54.6% Black (AR average 14.8%)
- Located in Delta area on Mississippi R.
- Traditionally agricultural - rice, cotton, soybeans - historically plantations

Explosion

- Azinphos-methyl (AZM)
  - Highly toxic, persistent insecticide
  - Organophosphate similar to nerve agent
  - Restricted Use Pesticide (RUP)
- Normally stable chemical likely delivered in unstable condition to plant site, reacted inside plant
- Spark of unknown origin ignited fumes

Incident

- Firefighters respond at 1:10 p.m.
- 1:30 p.m. explosion occurs - kills 3 firefighters, injures 17 others
- Residents in 2 mi. zone told to evacuate
- Residents in 2-3 mi. zone told to shelter
- Regional medical facility evacuates
- Residents allowed to return 10:00 p.m.
- Fires burn sporadically for next 3 days

Objectives of study

- To examine resident's response to warnings to evacuate or to shelter
- How were people warned?
- When did people leave?
- Where did evacuees go?
- What did people who sheltered do?
- Did people do as they were warned?

Approach

- Conducted interviews
  - First responders, plant managers, local emergency and fire officials, radio hosts, hospital personnel
- Obtained mailing addresses from 911 data base to use as sampling frame
- Mapped study populations via GIS
- Questionnaires mailed to census sample
- 64% return

How were people warned?

- 36% by officials (police, fire, emergency services, sheriff)
- 25.6% by neighbor, friend, co-worker
- 20.8% by family member or relative
- 4.9% by media (television or radio)
- 9.6% (of 131 responses) received more than one warning

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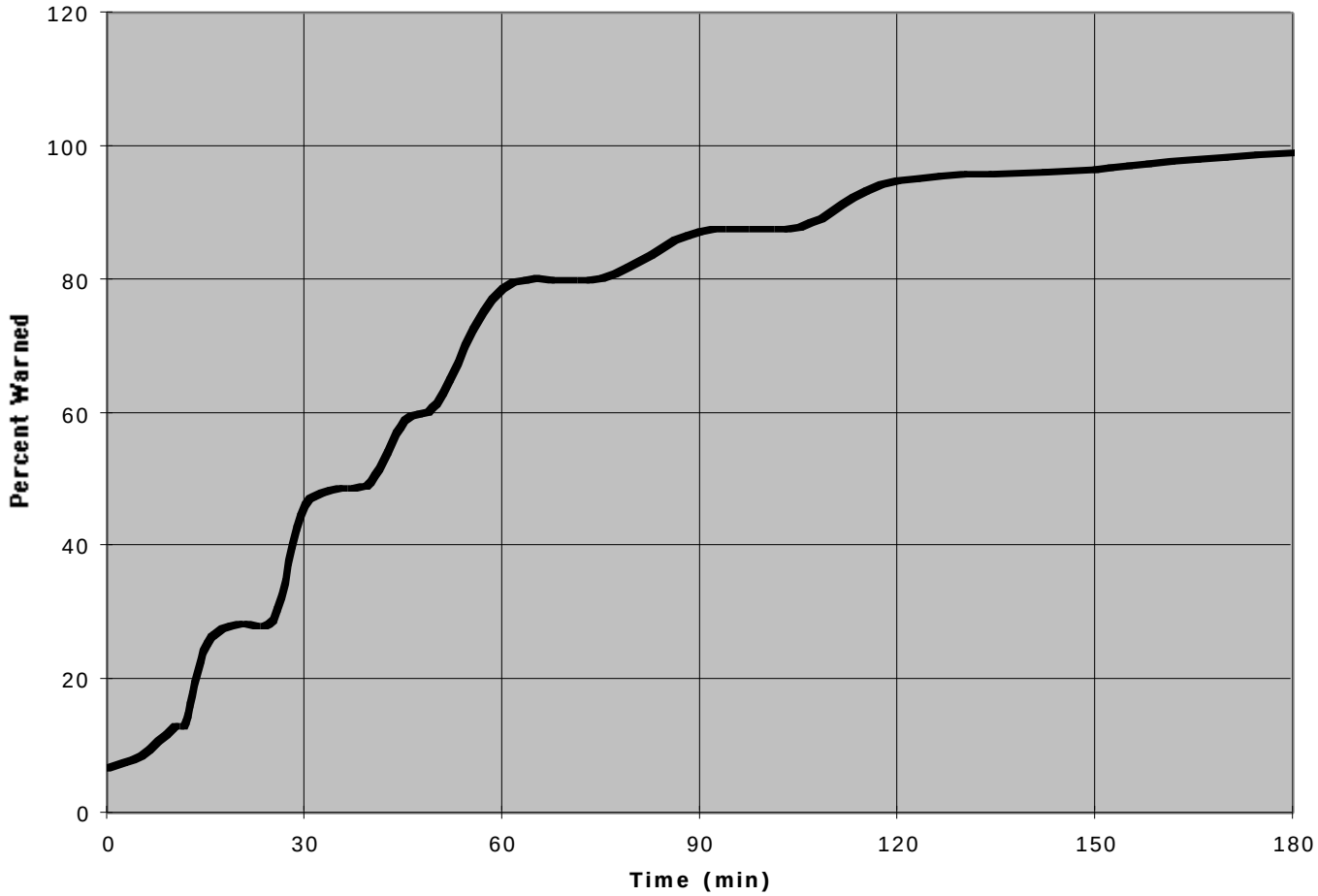
When were people warned?



Where did evacuees go?

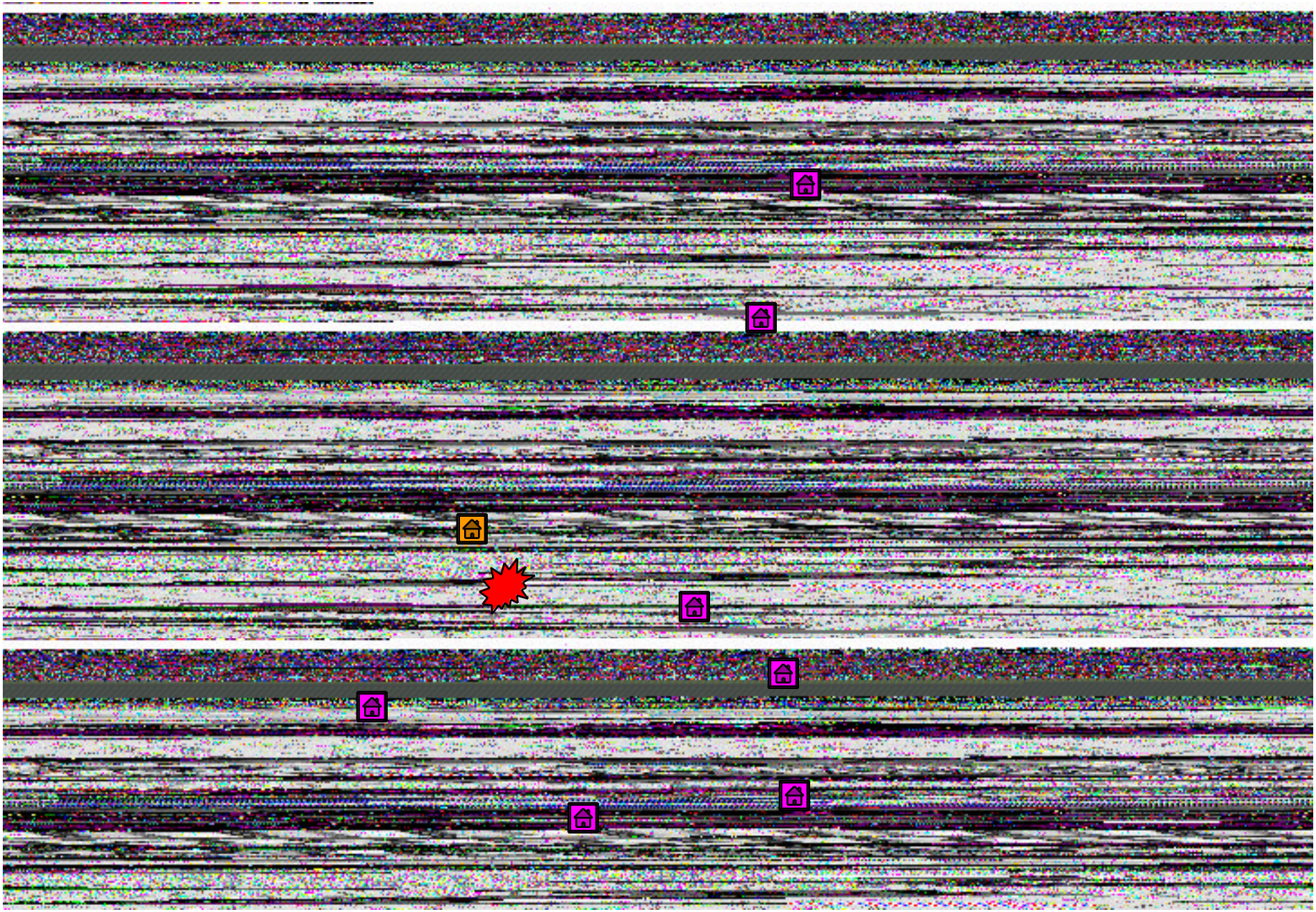
	Number of responses	Percent of total
Relative's residence	64	51.2
Friend's residence	18	14.4
Public shelter	1	0.8
Hotel or motel	12	9.6
Other	9	7.2
Missing/NA	21	16.8

What did shelterees do?

- Actions taken when sheltering
  - closed doors and windows
  - turned of heat/ac
  - taped windows
- Actions taken after sheltering
  - vented residence
  - took care of animals
  - called friends/relatives
  - listened to media
  - washed household items
  - showered or bathed

Compliance with warnings

	Evacuated	Sheltered	Neither evac. or sheltered	Total number responses
Evacuation area	90% (87)	5% (5)	5% (5)	97
Sheltered area	68% (18)	27% (7)	4% (1)	26
Percent of total responses	85% (103)	10% (12)	5% (6)	123



Was sheltering a good recommendation?

- Sheltering likely misunderstood by both officials and the public
- Conditions for effective sheltering must be established prior to accident
  - Infiltration rate of structures important
  - Warnings must include why/when to vent
- Compliance may be low - then what?
  - Quick moving event
  - Slows evacuation

Findings

- Respondents did what they perceived to offer best protection
- People likely won’t shelter if they see others leaving
- No decision criteria used for recommended actions -- most housing in shelter areas likely inadequate
- Need pre-planned decision

Lessons Learned

- Dual warnings require careful planning
  - Must be logical and consistent
  - May require substantial public education
- Coordinated and rapid response to accidents is essential
- GIS models can be developed to indicate suitable and unsuitable areas for sheltering

Disadvantages of Shelter-in-place

- Non-pressurized shelters not effective for long duration plumes.
- Requires aggressive public education effort to convince people to implement shelter-in-place and then to leave or ventilate shelter when recommended.
- Non-pressurized shelters require that local authorities have capability to determine when plume has passed a given area and to notify shelter inhabitants to leave or ventilate.

Advantages of Shelter-in-place

- Fairly quick implementation
- Effective at reducing peak concentration
- Effective at reducing cumulative exposure for limited duration
  - approximately 30 min. for normal shelter
  - 1-3 hours for enhanced/expedient
  - up to limit of filter for pressurized