PREVENTION THROUGH DESIGN

IN COLLABORATIVE RESEARCH ENVIRONMENTS

PURDUE UNIVERSITY
Discovery Park

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The Presentation

- What is Prevention through Design ?
- The Value of PtD in Meeting Safety Challenges
- Implementation of PtD: Real-World Examples
- Integrating Engineering Controls with Procedural Controls
- Summary

What is Prevention through Design ?

- A NIOSH* initiative
  - Launched July, 2007
  - Involves industry, academia, and government
  - Cooperative program to reduce workplace injuries, illnesses, and fatalities
- Addresses workplace hazards through design
  - Facilities
  - Practices
  - Processes
  - Materials

** National Institute of Safety and Health*

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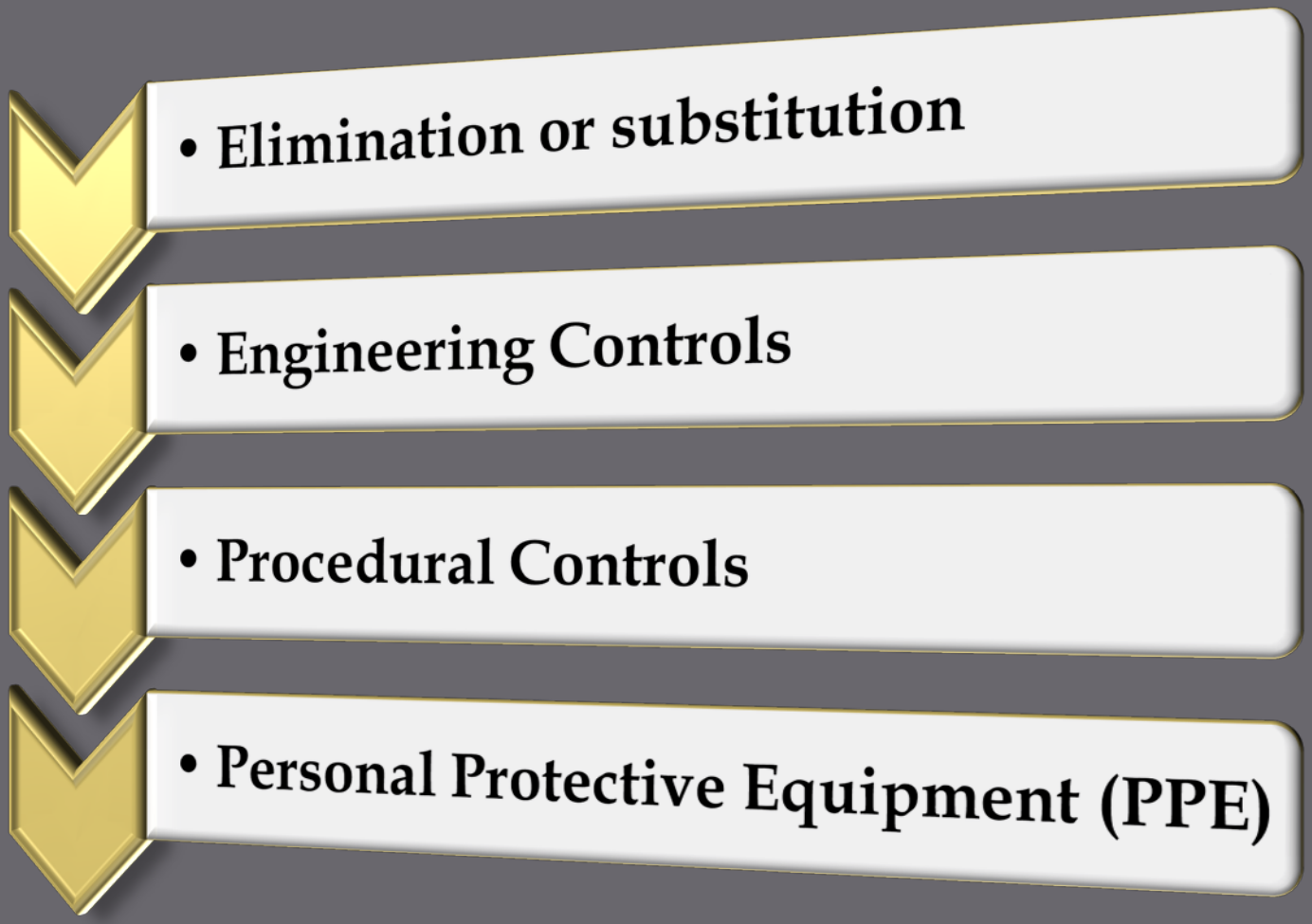
Prevention Through Design

- *NIOSH defines PtD as:*
  - *Addressing occupational safety and health needs in the design process to prevent or minimize the work-related hazards and risks associated with the construction, manufacture, use, maintenance, and disposal of facilities, materials, and equipment.*

Prevention through Design

- Consider safety in earliest design stages
  - Risk analysis
  - Overall safety plan
- Implement controls throughout the design process
  - Safety hierarchy
  - Designing in safety
- Implement the designs during construction
  - Bid process and submissions review
  - Systems installation
- Commission the safety systems
  - Ensure proper performance
  - Debug and repair process

Safety Hierarchy



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Elimination or Substitution

- The elimination of the material or equipment causing the risk.
  - Preferred solution for dealing with risks
- Achieved through:
  - Process and equipment modifications
  - Substitution of nonhazardous materials for the hazardous materials
- Example of substitution
  - Use of material quantities or concentrations that cause the material to fall below the hazard threshold

Engineering Controls

- Devices that prevent exposure to the hazard
- Used when elimination or substitution is not practical
- Designed to control the hazard without effort by the person using the equipment or material
- May be active or passive in nature
  - If active they should be automatically activated when the hazard or the person is present.

Procedural Controls

- Least desirable hazard controls
- Require activation by the person using the equipment or materials
  - Susceptible to failure.
- Sometimes necessary
  - Far more desirable to implement engineering controls or eliminate/substitute the hazard.

Personal Protective Equipment (PPE)

- Used as a procedural control to minimize hazards
- Used to provide a second level of safety when engineering controls are used.

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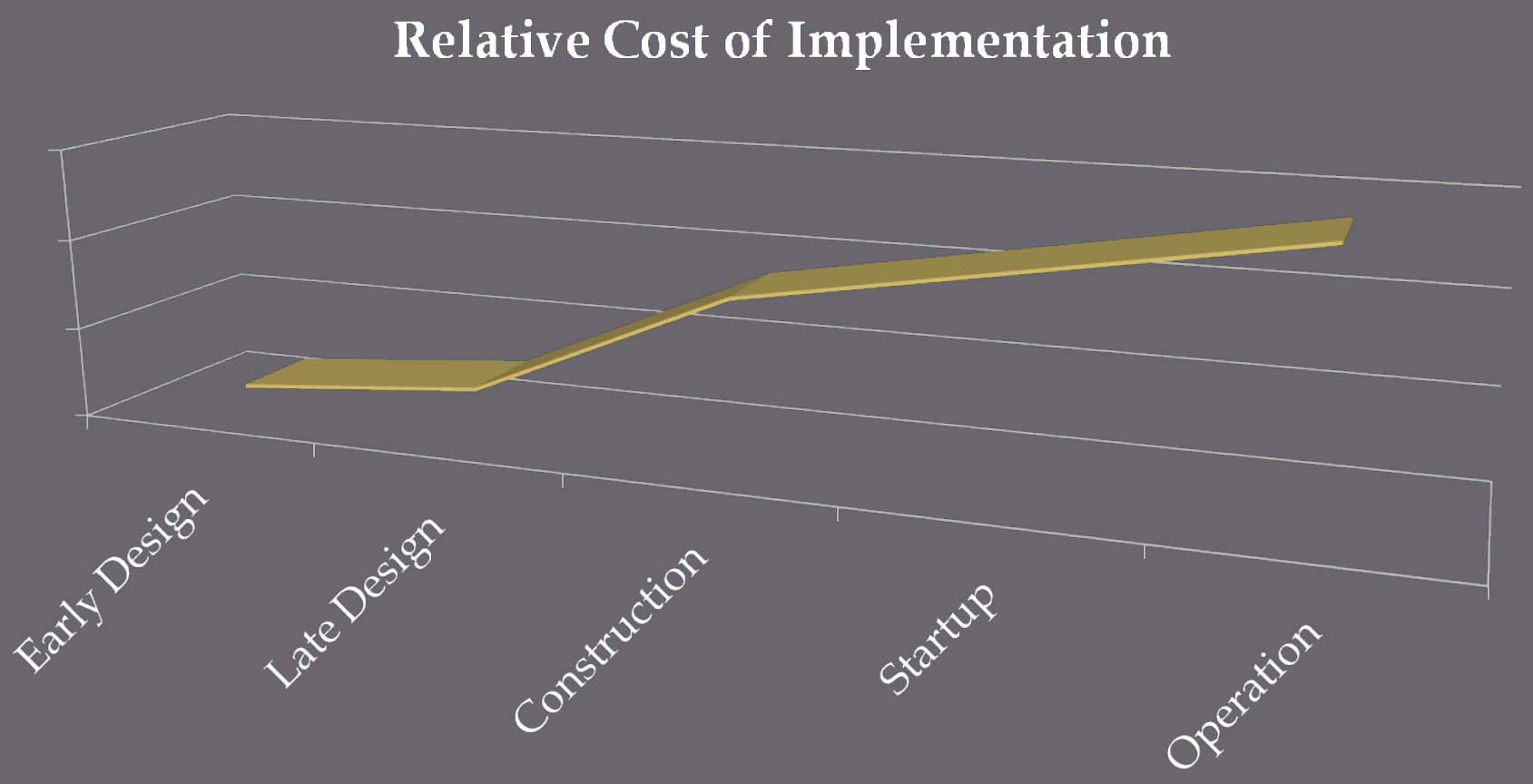
Why Use Prevention through Design?

- Cost effective
  - Cost of implementation increases through project duration
- Capability
  - Many controls cannot be retrofitted – must be designed into the system
  - Less need to compromise on type of control if designed in from the beginning

Cost of Implementation



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PtD Summary

- Prevention through Design is a major NIOSH initiative
- Can be applied to facilities, equipment, procedures, processes, products, and materials
- Stresses the need to consider safety early in the design cycle
- Provides better cost effectiveness and increased capability of control implementation

Prevention through Design

- Utilize engineering controls as primary control
- Use operational controls for secondary control (redundancy)
- Implement these controls in the design phase
- Can be designed into original or retrofit to existing
  - Building
  - Process
  - Product

In short:

Make it easier to do it the safe way!

What is PtD?

The easiest way to describe PtD is to show it in action

- Vignettes of PtD solutions to facility issues
- A "deep dive" into PtD solutions for gas-hazard mitigation

Problem: *Safety glasses required*

- Safety glasses are required in many areas
- Violations of policy are common
  - Person forgets to bring glasses to lab
  - Person entering lab to "pick up something" and does not bring glasses
  - Visitors touring lab, guide did not bring glasses
- Can result in eye injury even when in lab for a short time
- Degrades general laboratory discipline

PtD Mitigation: *Safety glasses stocked at laboratory entrance*

- Safety-glasses holders with spare safety glasses are located inside the door of each laboratory or other area where safety glasses are required
- User returns glasses to holder when exiting
- Stock levels inspected and replenished weekly

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Problem: *Building Alarm Systems*

- People must remember the meanings of various alarm tones
  - "Evacuation tone" vs. "Take Cover" tone
  - No international standard on tones – different companies and universities have different tones for different warnings
- During an emergency situation, people don't always think clearly
- Significant risk accompanies incorrect interpretation of an alarm tone
  - Taking cover in building during an evacuation
  - Exiting the building during a tornado alarm

PtD Mitigation: *Alarm System Design*

- Tone with spoken instructions for evacuation
  - Identifies type of emergency
  - Gives specific instruction on what to do
- Text messaging system
  - Appropriate staff are notified of situation
- Communicates with Building Security System
  - Doors lock and unlock as appropriate

Building Security System
Response to Alarms

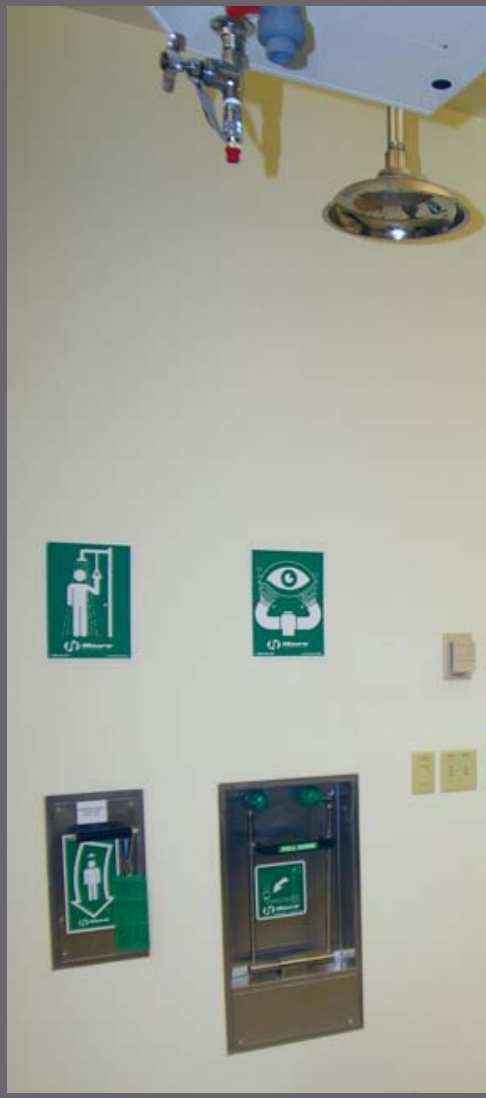
- Normal Operation
  - Public areas open during business hours
  - Nighttime access only to trained personnel
  - Laboratory and cleanroom access according to training
- Evacuation
  - Lock all outside doors
  - Unlock all inside doors
- Tornado Alarm
  - Unlock all outside doors
- Workplace violence incident
  - Outside doors to BNC employees only

Problem: *Summoning assistance during a laboratory emergency*

- A chemical exposure requires person to use an emergency shower-eyewash station
  - May need assistance but cannot communicate outside laboratory while in shower
  - Lab "buddy" may not be immediately available
  - Lab "buddy" may be occupied in helping person in shower

PtD Mitigation: *Flow-Monitoring of Eyewash Stations*

- Building control system monitors the flow in an eyewash – safety shower station
  - Eliminates human intervention in summoning help
    - Pages appropriate staff
    - Sounds alarm as required
  - Logs activity, time-stamp for an incident
    - Useful in after-incident evaluation



Problem: *Enforcement of Training Completion*

- Training courses are required
  - After-hours building access
  - Laboratory access
    - Courses depend on hazards present in laboratory
  - Cleanroom access
  - Biocleanroom access
- It is difficult to enforce completion of training courses
  - Faculty
  - Students
- Training expires after period of facility non-use
  - Difficult to enforce refresher compliance

PtD Mitigation: *Access Dependent on Training Completion*

- Office keys (including faculty) issued only on completion of building training
- Laboratory, cleanroom, biocleanroom access allowed on completion of training
- Building security system ensures compliance
  - Access card issued during completion of building training
  - Card activated only for areas where requisite training has been completed
  - Card deactivated when training has expired

Problem: *Liquid chemicals must be transported to point of use*

- Liquid chemicals staged in chemical storage room near point of delivery
- Chemicals must be transported from this location to their point of use
- Vulnerable to an incident that would result in a spill
  - Dropped chemical bottle
  - Leaking chemical bottle
  - Collision with transport cart
    - Especially during an emergency evacuation

PtD Mitigation: *Liquid Chemical Protection*

- Overpacks
  - Special design protects from breakage and contains leaks and spills
  - Two-piece design cannot be used independently
- Containment carts
  - Contains at least the volume of the largest container being transported on cart

PtD Mitigation:
Liquid Chemical Delivery Route

- Transport path that does not cross exit corridors
  - Emergency exits on either side of transport corridor
- Dumbwaiter to cleanroom
  - Unmanned transportation route

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Problem: *A liquid spill event gives off vapors*

- Vapors given off by liquid spill can cause problems to facility and/or its occupants
  - Corrosive vapors damage nearby equipment
  - Toxic vapors cause health risks
- Vapors often exhausted through equipment enclosures
  - Damages components when passing through enclosure
  - Endanger people between spill and enclosure

PtD Mitigation:
Designing for an Emergency

- Emergency exhaust systems
  - Fixed exhaust
  - "Flexible" exhaust

Problem: *Access to critical equipment settings*

- Hazards can be created by unauthorized people changing equipment settings
  - Gas valves and flow settings
  - Electrical connections and power
  - Interlocks and safety settings

- Motivated by user "trying something new" to perform specialized experiment

PtD Mitigation: *Equipment Controls*

- Bulkhead mounting of equipment
  - Operations access from cleanroom bay
  - Maintenance access from chase
  - Only staff are allowed in chase
- Uses fixed barrier rather than procedural control

Problem: *Use of Hazardous Gaseous Processing Materials*

- Pyrophoric gases / Detonable gases
  - Silane
  - Germane
- Flammable gases
  - Hydrogen
  - Dichlorosilane
  - Methane
- Toxic gases
  - Arsine
  - Phosphine
  - Fluorine
  - Chlorine
  - Boron Trichloride
  - Hydrogen Chloride
  - Nitric Oxide
  - Nitrogen Dioxide
- Non-hazardous gases
  - Nitrogen
  - Helium
  - Argon
  - Oxygen

PtD Mitigation: *Facility Designs to Reduce Risks from Hazardous Gases*

A Systematic Application of Prevention through Design Implementation

A "Deep Dive" into PtD

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The Hierarchy
Applied to Gas Hazard Mitigation

- **Prevention**
  - Building security design
  - Separate dock area
  - Outdoor storage area
  - Pyrophoric bunker
  - Flammable and toxic gas rooms
  - Gas Cabinets
  - Distribution System

Engineering Controls

Prevention ≡> Monitoring ≡> PPE

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The Hierarchy
Applied to Gas Hazard Mitigation
(CONTINUED)

- **Monitoring**
  - Monitoring Systems
  - Automated Response

Engineering Control

- **Emergency shut-off**
- **Personal Protective Equipment**
  - Air packs
  - Air-Line Cart

Procedural Controls

Prevention => Monitoring => PPE

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Building Security Design
Engineering Controls

- Card-Access levels
  - Public spaces distinct
    - Laboratory security
    - Cleanroom security
    - Support areas
- Special keys/access
  - High-hazard areas
  - High-vulnerability spaces
- Camera systems
  - Recording devices for documentation
- Automation during emergency
  - Lock all exterior doors
  - Unlock all laboratory doors
  - Supplemented by "door guards"

Building Security
Procedural Controls

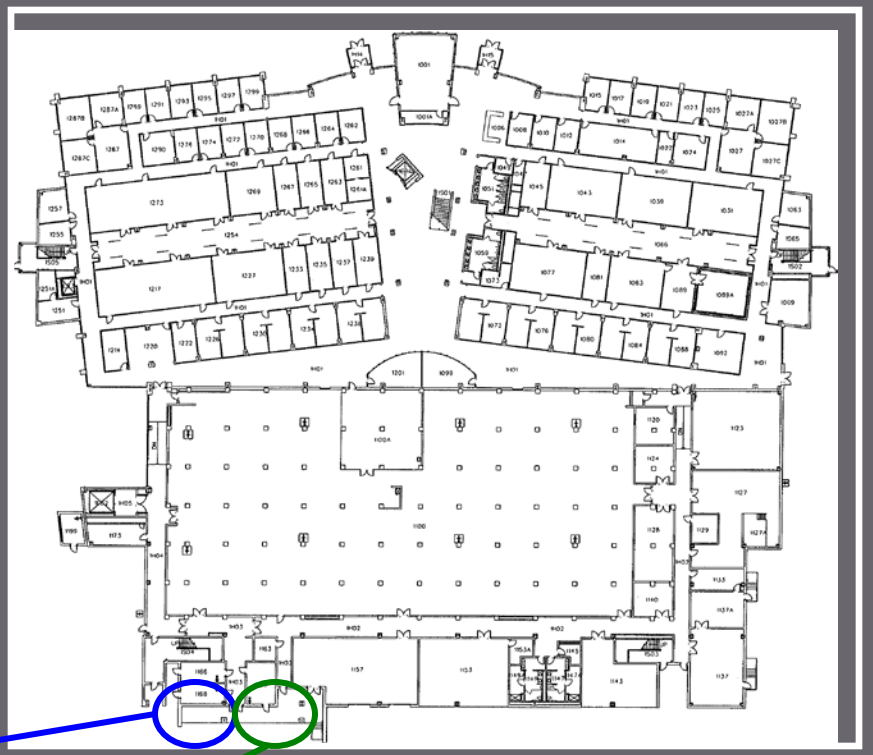
- Card-Access levels
  - Cultural change: Access is not prestige
- Discipline for Circumventing Security
  - Propping open doors
  - "Tailgating" into secure spaces
- Access recordkeeping
  - Provides documentation for discipline
  - Assists in after-incident analysis

Problem: *Dock Area Traffic with Hazardous Chemicals Present*

- Typical dock area
  - Fork-truck traffic
  - Large-equipment movement
  - Numerous deliveries throughout day
- Staging area
  - Location of materials and equipment prior to movement to final location
  - Items may be present for extended periods
- Access Requirements
  - Untrained personnel (e.g., truck drivers)
  - Pedestrian traffic

PtD Mitigation: *Separate Dock Area and Outdoor Staging Area*

- Used for loading and unloading chemicals only
- Outside of building traffic patterns
- Locked staging areas
- VERY limited access to staging areas



Chemical Dock and Gas Storage

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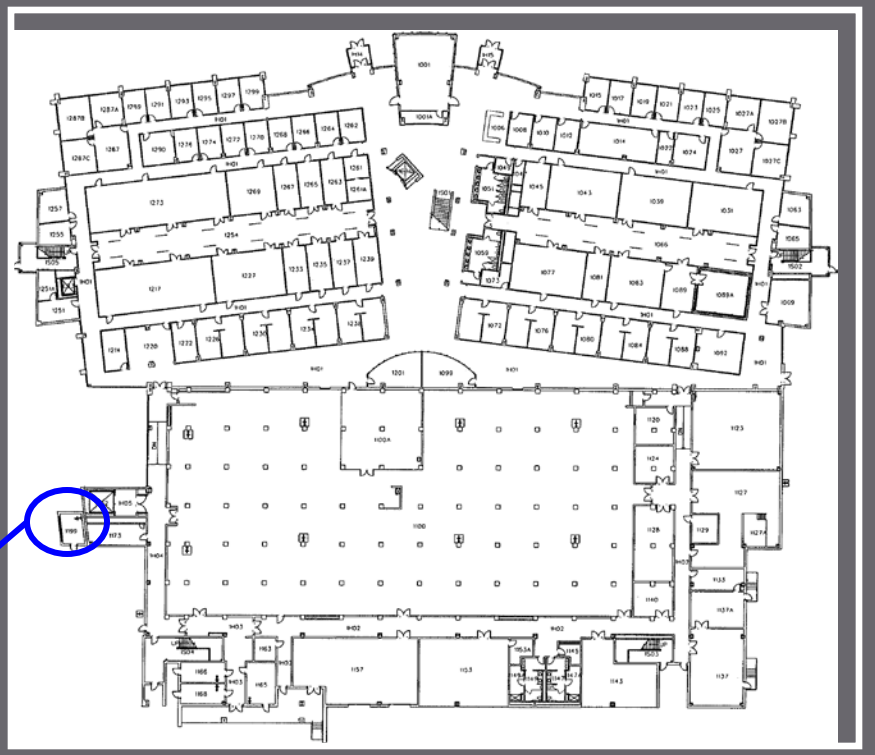
Problem: *Pyrophoric and Detonable Gases*

- Pyrophoric gases required
  - Spontaneously ignite when in contact with oxygen levels present in air
- Detonable gases
  - Some pyrophoric gases (e.g., silane) are detonable
  - Pocket without burning
  - Detonate when mixed with air
  - Lethal pressure wave when detonation occurs

PtD Mitigation: *Pyrophoric bunker*

- Poured concrete structure
- Blow-out wall and ceiling
- Remote purging
- Very limited access



Pyrophoric Bunker

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Problem: *Toxic and Flammable Gases*

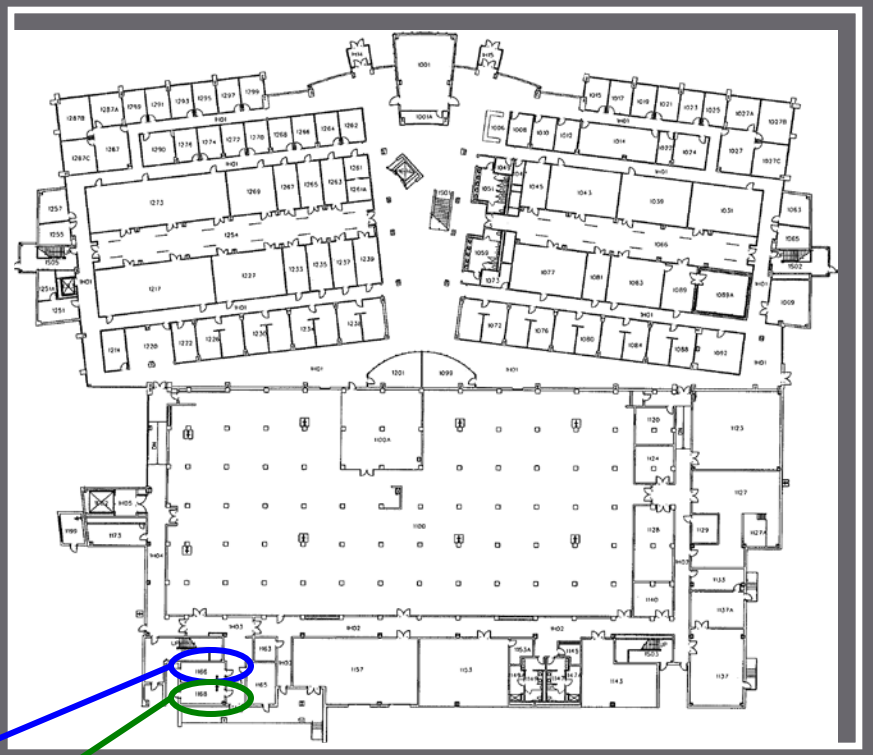
- Toxic and flammable gases needed
  - Highly toxic gases like arsine and phosphine
  - Flammable gases like propane and methane

PtD Mitigation: *Isolation and Protection*

- Isolation
  - Primary control: Gas Cabinets
  - Secondary control: Gas Rooms
- Protection
  - Distribution system
  - Monitoring systems
  - Emergency shutoff
  - PPE

Flammable and Toxic Gas Rooms

- Separate rooms for flammables and toxics
- Explosion-proof construction
- Very limited access
- Close to chemical dock and storage



Gas Cabinets

- Gas cabinets are required for all hazardous gases (3 or higher on the NFPA scale)
- Automated operation to ensure proper purging
- Redundant safety features with emergency shut-down
  - Excess flow
  - System failure
  - Reduced-flow orifice
- All cabinets contain fire sprinklers
- High exhaust flow – 200 cfm – at 0.02 in. H2O

Gas Cabinet Exhaust

- Magnahelic gauge on cabinet exhaust
  - Visual display that exhaust is functional
  - Redundant with automatic cabinet shutdown

Distribution System

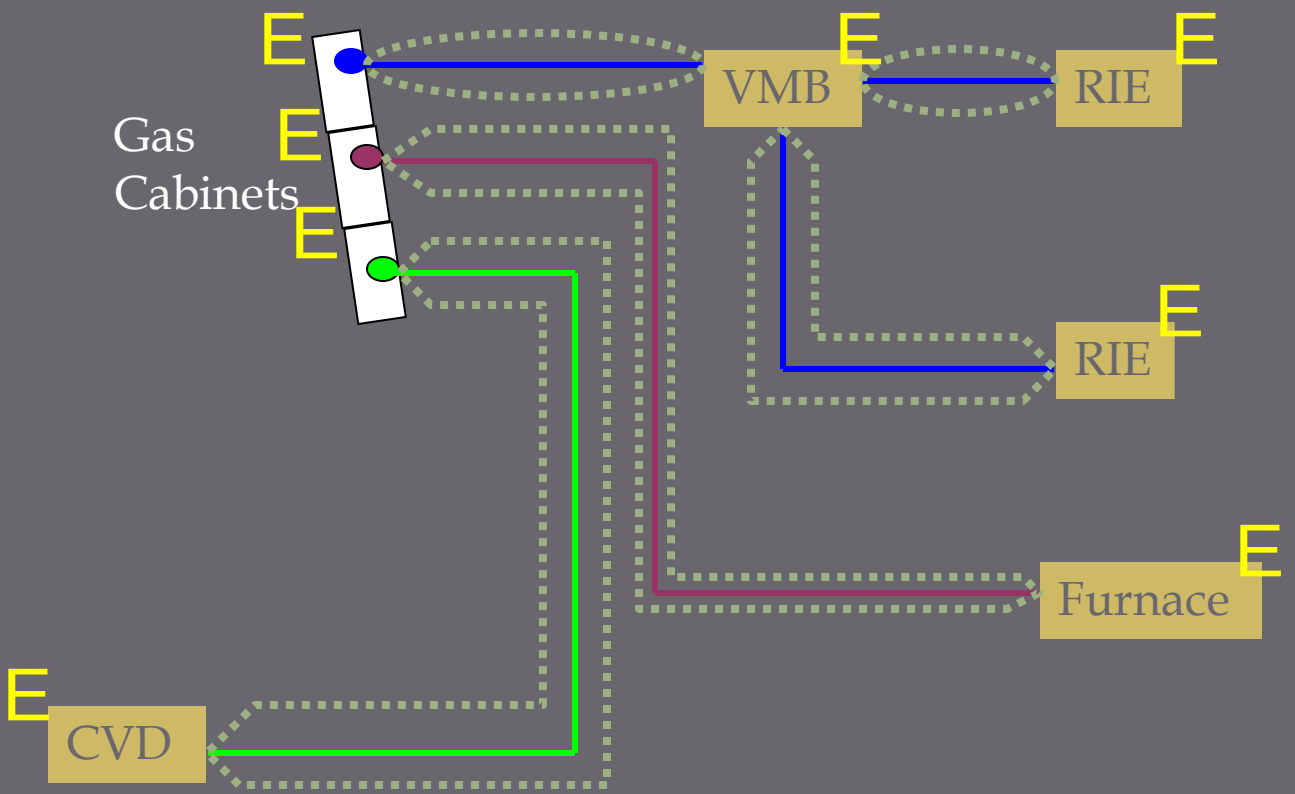
- Doubly contained piping
  - Coaxial stainless steel piping
- Protected overhead runs
- Rigorous welding requirements
  - certified welders
  - certified welds

Monitoring Systems
for hazardous gases

- Sensing ("sniffing") System
  - Senses presence of hazardous gas
  - Used where there is single containment
    - Points of delivery
    - Points of use
- Interstitial-Pressure Monitoring
  - Used to monitor double-containment efficacy

Monitoring Schematic

E Gas sensors immediately downstream



Individually Monitored Section of Continuous Piping

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Gas Sensing

- Hazardous-gas monitoring system
  - Senses gases in low concentration
  - 72 detection points
  - Three different families of gases
    - Hydrides
    - Halides
    - Chemical-specific
  - Two levels of alarm
    - Danger (Evacuate) = 100% TLV
    - Warning (Page) = 50% TLV

Gas Sensing (continued)

- Used in areas of single containment
  - Gas cabinets
  - Valve-Manifold Boxes (VMBs)
  - Equipment enclosures
- Monitor in exhaust duct immediately downstream from potential leaks
  - High turbulence area
  - Complete mixing of exhaust
  - More likely to sense a leak than inside a cabinet

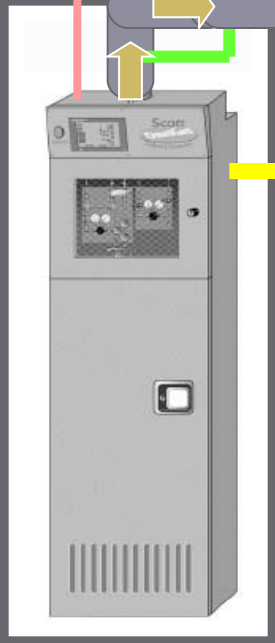
Gas Sensing Locations

Vertex

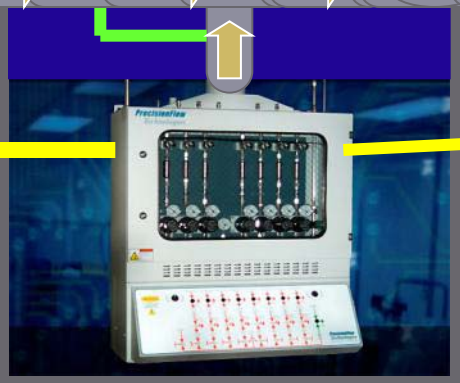
Detector

Gas Detection Line

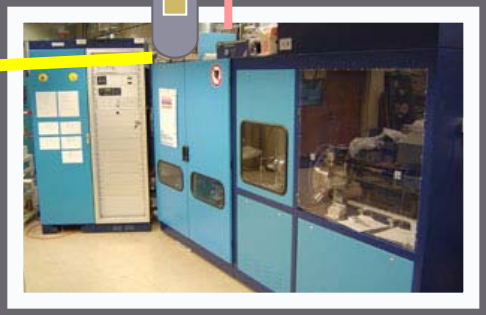
Purge Discharge Line



Gas Cabinet



VMB



CVD

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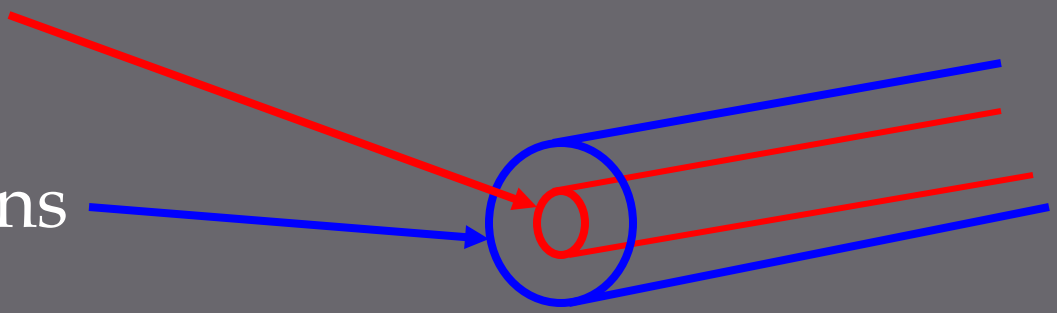
Doubly contained piping

- Inner piping carries hazardous gas
- Outer piping contains inert gas (Ar)



- Outer gas is 50% the pressure of the inner gas
  - Pressure rise indicates leak in inner piping
  - Pressure drop indicates leak in outer containment
  - Pressure to zero indicates catastrophic failure
- Real-time monitor tracks pressure and initiates action

Actions in Event of a Dual-Containment Alarm

- Rise or fall of interstitial pressure
  - No hazard exists
    - Bleed-down of pressure
    - Breach in redundancy
  - Text message to appropriate staff
- Interstitial pressure goes to zero
  - Catastrophic failure of piping
  - Potential for high hazard
  - Evacuate facility
  - Shut off gases at cylinder valve

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Integration of Monitoring Systems

- Pressure Monitoring System

ties into

- Gas Sensing System

ties into

- Fire Alarm System
  - Paging of first responders
  - Building evacuation annunciation
  - Summoning emergency responders – police and fire

Emergency Gas Shut-Off

- Mushroom switch with protective cover
- Located at exits where hazardous gases are used
- Shuts down all hazardous gases at their source
- Sounds building evacuation alarm

Procedural Control

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Personal Protective Equipment

- Self-Contained Breathing Apparatus (SCBA)
  - Air-pack for short-term maintenance and cylinder changes
- Air-Line Cart
  - Long-term supply air for extended maintenance activities

Procedural Control

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Summary

- A population of diverse cultures and technical backgrounds provides particular challenges to occupant safety.
- The NIOSH Prevention through Design initiative provides a method for mitigating risks through design elements rather than procedural controls
- Procedural controls are used as a secondary element – redundancy – in the development of workplace safety systems

Acknowledgements

- The design-for-safety concepts executed in the Birck Nanotechnology Center were – and are – a major team effort. Some key members who created the designs shown in this presentation are:
  - The BNC Engineering Staff – 28 of the best engineers and scientists with whom one could ever work!
  - Purdue Radiological and Environmental Management
  - Purdue University faculty involved in nanotechnology
  - HDR Architecture