THE TREATMENT OF DOMINO EFFECTS IN PROCESS HAZARD ANALYSIS

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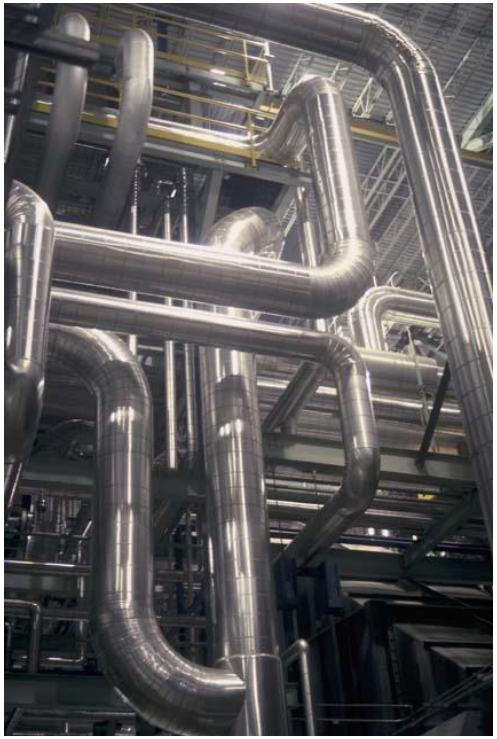
OVERVIEW

- Definition and meaning
- Importance
- Accidents
- Consideration
- Types
- Consideration
- Example



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DEFINITION OF DOMINO EFFECTS

- Primary event, such as an explosion
  - Triggers secondary events, such as toxic releases
    - Results is an increase in consequences

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MEANING OF DOMINO EFFECTS

- Hazard scenario involving cascading consequences
  - Often escalating, branching, and extending spatially
- Linked sequence of events propagates throughout and beyond the process
- One hazard is realized
  - Triggers one or more additional hazards of the same or different types
- Multiple consequences occur serially
  - Primary, secondary, and higher-order
- Direct result of one initiating event

IMPORTANCE OF DOMINO EFFECTS

- Played a role in numerous accidents
  - Recent paper identified 224 incidents from 1917 to 2009
- Consequences are amongst the greatest that can occur in process facilities
  - Often involve multiple fatalities
  - Have destroyed entire facilities
- Neglecting domino effects will underestimate process risk

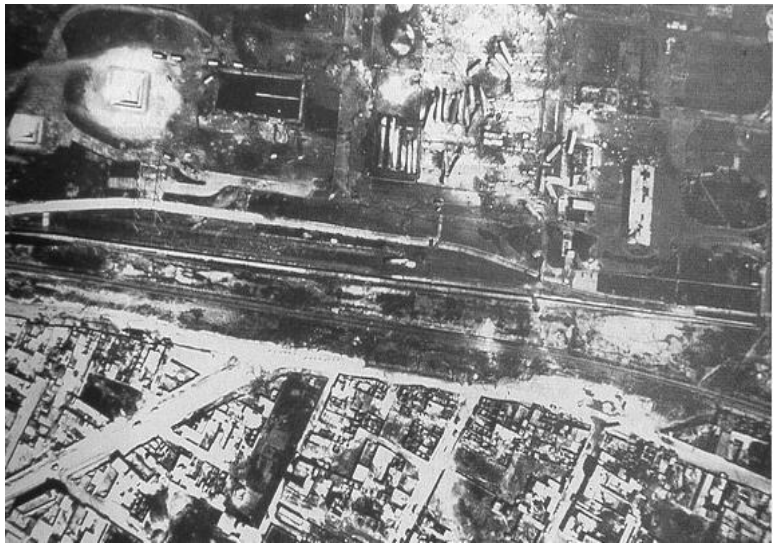
OIL STORAGE DEPOT, FIRES AND EXPLOSIONS – JAIPUR, INDIA, 10/29/09

- 6 fatalities
- 150 injuries
- $30M lost product
- Facility destroyed
- Adjoining factories destroyed

POLYVINYL ACETATE PLANT, FIRES AND EXPLOSIONS – YIZHOU CITY, GUANGXI, 8/26/08

- 16 fatalities
- 57 injuries
- 11,500 people evacuated

LPG TERMINAL, FIRES AND EXPLOSIONS, MEXICO CITY, MEXICO, 11/19/84



- 600 people killed
- 7,000 people injured
- 200,000 people evacuated
- Terminal destroyed

CONSIDERATION OF DOMINO EFFECTS

- Quantitative Risk Analysis (QRA) approaches have been developed
  - Predicated on assumed events, not scenarios
    - Do not address more subtle initiators that can be identified with PHA
  - Not commonly used
- Received less attention in Process Hazard Analysis (PHA)
- Essential that PHA address possible domino effects
  - Identify specific scenarios
  - Evaluate and address their contribution to process risk

CONSIDERATION OF DOMINO EFFECTS (CONTD.)

- QRA primarily looks outwards
  - From the source of the domino effect to the target or receptor
- PHA can look both outwards and inwards
  - From the target back to the source
  - Helps to identify domino scenarios as completely as possible

TYPES OF DOMINO EFFECTS

- Fire
- Explosion
- Toxic material release
- Other hazardous material release
- Physical effects

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DOMINO EFFECTS - FIRE

- Result from *thermal radiation* or *flame impingement*
- Fire may induce mechanical failure of equipment that contains hazardous materials
  - E.g. Jet fire from a tank impinging on an adjacent tank causing its rupture
- Fire may heat the contents of process equipment producing a release
  - E.g. Heat radiation from a pool fire at a leaking tank causing the over-pressurization failure of an adjacent tank

DOMINO EFFECTS - EXPLOSION

- Result from *overpressure*, *or blast wave*, and from *projectiles*, *or missiles*
- Primary projectiles may result from:
  - Fragmentation of equipment
  - Separation and rocketing of equipment
  - Ejection of an object from equipment
- Secondary projectiles result from the explosion blast wave imparting energy to objects in its path

DOMINO EFFECTS - TOXIC MATERIAL RELEASE

- Result from:
  - Incapacitation or degradation in the performance of personnel
  - Need for evacuation
  - Prevention of access to a process area
- For example, toxic material release may prevent an operator from activating the emergency shutdown

DOMINO EFFECTS - OTHER HAZARDOUS MATERIAL RELEASE

- Result from the inadvertent release of other hazardous materials
  - Through their impact on the process or its personnel
- For example, leakage of corrosive material may cause a failure of another piece of process equipment and the release of a hazardous material
- Typically, PHA teams focus on direct causes of releases
  - Leaks from piping, valves left open, etc.
- Indirect causes from domino effects may be missed by a PHA team
  - Unless they are considered explicitly

DOMINO EFFECTS - PHYSICAL EFFECTS

- Produced through the impact of various physical effects on the process or its personnel
- For example:
  - A high-pressure gas jet may impinge on process piping or vessels resulting in their failure owing to low temperature embrittlement
  - Hose whipping may incapacitate people or damage equipment
  - Failure of rotating equipment may generate projectiles

DIRECT VERSUS INDIRECT DOMINO EFFECTS

- *Direct effects:*
  - Domino event results in an immediate escalation of the scenario consequences
- *Indirect effects:*
  - Domino event causes an impact that leads to escalation

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EXAMPLES OF IMPACTS LEADING TO ESCALATION

- Loss of process control systems, e.g.
  - Basic process control system (BPCS)
  - Safety instrumented system (SIS)
- Loss of mitigation systems, e.g.
  - Disabled fire protection system

CONSIDERATION OF DOMINO EFFECTS IN PHA

- Usually domino effects are considered as external events in PHA
  - Approach looks inwards
- PHA teams may not recognize that the domino effect is part of a chain and that further domino effects may be possible
  - Domino event may be a tertiary or higher-order event in a domino scenario

CONSIDERATION OF DOMINO EFFECTS IN PHA (CONTD.)

- Inward-looking approach causes the PHA team to focus on large direct domino effects
  - May miss lesser and indirect domino effects
- Consequences of the scenario may be underestimated if domino events are considered individually
  - Rather than as a super event

CONSIDERATION OF DOMINO EFFECTS IN PHA (CONTD.)

- Preferable to begin the identification of domino scenarios with an approach that looks outwards
- PHA teams should brainstorm possible initiating events for domino scenarios
  - Examine how their consequences may extend beyond immediate impacts
- Successive domino events should be traced throughout process, and beyond
  - To the extent feasible

CONSIDERATION OF DOMINO EFFECTS IN PHA (CONTD.)

- Include scenarios with immediate consequences of low severity that may result in domino scenarios with consequences of high severity
- For example:
  - Rupture of a small diameter pipe may result in a small jet fire
    - Immediate consequence of low severity
  - If the jet fire impinges on a storage tank, a Boiling Liquid Expanding Vapor Explosion (BLEVE) may result
    - Produces much greater consequence

CONSIDERATION OF DOMINO EFFECTS IN PHA (CONTD.)

- PHA is not the place to explore all the possible paths and branches of domino scenarios
- At best, PHA may be able to identify effects clearly up to secondary events
  - And the possibility of higher-order ones
- Exploration of higher-order events would sidetrack the team from their primary responsibility
  - Identifying initiators of domino scenarios
- Consequently, domino effects also should be addressed in separate studies or in facility siting studies

APPLICATION USING AN ACCIDENT

- On February 16, 2007, liquid propane was released from piping in the Propane DeAsphalting (PDA) unit at Valero's Refinery near Sunray, Texas
- Resulted in a major fire:
  - Injured three employees and a contractor
  - Caused extensive equipment damage
  - Required the evacuation and total shutdown of the refinery

DOMINO EFFECTS IN THE ACCIDENT

- Rapidly expanding fire prevented operators from closing manual isolation valves or reaching local pump controls
  - Might have been used to control the propane discharge (indirect)
- Propane jet fire impinged on a non-fireproofed steel pipe rack support
  - Buckled causing multiple pipe failures (indirect)
- Discharge of petroleum products from the damaged pipes escalated the fire
  - Caused further damage to surrounding equipment (direct)
- Responders were unable to activate fire water monitors
  - Because of high and shifting winds and the rapid growth of the fire (indirect)

DOMINO EFFECTS IN THE ACCIDENT (CONTD.)

- Chlorine containers were exposed to radiant heating from the fire and vented (direct)
- Fire brigade could not enter the refinery owing to the chlorine release and leaks of sulfuric acid (indirect)
- Radiant heat from the PDA fire blistered the paint on butane storage sphere (direct)
- Responders were unable to reach the manual firewater deluge valves for the butane sphere owing to heat from the fire (indirect)

PHA AND THE ACCIDENT

- The Chemical Safety Board (CSB) report on the incident found fault with the refinery's PHA
  - PHA did not identify and address hazards posed by fire exposure to neighboring equipment
    - Including the chlorine containers and the butane storage sphere

PHA AND THE ACCIDENT (CONTD.)

- Few PHA teams likely would follow a domino scenario through all the steps in the accident
  - Reach a point where further escalation is viewed as incredible
  - Rely on recommendations that prevent further escalation

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CONCLUSIONS

- Domino scenarios are important contributors to process risk
- Their identification must be addressed in PHA
- Traditional PHA approach of looking inwards must be supplemented by an approach that looks outwards
- Scenarios identified with PHA should be examined in more detail using QRA methods