Fire Protection Design

Prescriptive Design
- Codes
- Standards
- Specification

Deterministic Design
- Fire Scenario (severity)
- Specification
- Performance based

Probabilistic Design
- Fire Scenario (severity)
- Risk of events
- Specification
- Performance based
Deterministic vs Probabilistic

NFPA 551 Definitions:

Deterministic Model:
In a deterministic model, the quantities being modeled are treated as being completely certain — the purpose of the model is to provide an estimate of these quantities.

Probabilistic Method:
In a probabilistic model, the quantities being modeled are treated as being uncertain — the purpose of the model is to quantify the degree of uncertainty in these quantities.
Defensive Fire Protection

NFPA 600 Definitions:

Defensive:
The mode of manual fire control in which the only fire suppression activities taken are limited to those required to keep a fire from extending from one area to another.

Offensive:
The mode of manual fire control in which manual fire suppression activities are concentrated on reducing the size of a fire to accomplish extinguishment.
Risk Based Fire Protection Design

Scenario Selection

Consequence & Freq. Analysis

Barriers Effectiveness

Event Tree Analysis

Risk Plotting
Event Tree Analysis

Leak Frequency

Ignition Probability

Immediate to Delay Ignition

Event Frequency

Loss of Containment

3.45 x 10^-3

3.38%

Immediate

50%

Delayed

50%

5.83 x 10^-3

VCE

Jet Fire / BLEVE

Dispersed Gas

96.62%

No Ignition

5.83 x 10^-5

3.33 x 10^-3
Reliability of Barriers

Reliability of the barriers depends on:

- failure frequency
- test intervals,
- mean time to restore (MTTR) and
- diagnostic coverage.

\[ PFD \approx \lambda_{DU} \cdot \frac{\tau}{2} \]
## Failure on Demands

<table>
<thead>
<tr>
<th>Type of Barriers</th>
<th>Failures (per 10⁶ hr)</th>
<th>Test Interval (yr)</th>
<th>Calculated PFD</th>
<th>Selected PFD (Based on Industry Practice)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas Detector (IR)</td>
<td>2.26</td>
<td>1</td>
<td>4.49×10⁻³</td>
<td>3.07×10⁻³</td>
<td>Test interval every 3 months. However, standard test interval is every year</td>
</tr>
<tr>
<td>Deluge System</td>
<td>5.8</td>
<td>1</td>
<td>1.27×10⁻²</td>
<td>1.5×10⁻²</td>
<td>Selected PFD is based on OGP</td>
</tr>
<tr>
<td>Diesel Fire Water Pump</td>
<td>1550.38</td>
<td>0.02</td>
<td>0.133</td>
<td>0.12</td>
<td>Poorly Maintained Diesel pump is 0.12</td>
</tr>
<tr>
<td>(Per NFPA weekly)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Passive Fire Protection</td>
<td></td>
<td></td>
<td>0.01</td>
<td></td>
<td>CCPS</td>
</tr>
<tr>
<td>Emergency Shutdown Valve</td>
<td>6.5</td>
<td>1</td>
<td>2.89×10⁻³</td>
<td>2.89×10⁻³</td>
<td></td>
</tr>
<tr>
<td>ESD Logic Solver</td>
<td>16</td>
<td>Unknown</td>
<td>3.5×10⁻²</td>
<td>3.5×10⁻²</td>
<td>Test Interval is normally 1 yr</td>
</tr>
</tbody>
</table>

30 January 2017
Effectiveness of Barriers

Effectiveness of barriers and safeguards should be evaluated by considering the following elements:

- Functionality;
- Maintenance History;
- Voting Logic; and
- Dependability.
Dependable Equipment Impairment
Functionality

- Deluge for BLEVE impingement (PFD=1)
- Using Improper type of fireproofing or jacketing (PFD=1)
Voting Logic

PFD = 4.98 x 10^{-2}
Voting Logic

No Depressurization:
- Sensor 1oo1 (Detectors, etc.)
- Logic Solver 1oo1 (ESD Logic / F&G Logic)
- Final Element 2oo2 (ESDV / Alarm)

PFD = 4.70 x 10^{-2}

Operator Intervention:
- Operator Intervention
- Logic Solver 1oo1 (ESD Logic / F&G Logic)
- Final Element 3oo3 (ESDV / Alarm)

PFD = 1.41 x 10^{-1}
Case Study: NGL Bullets

Fire Protection System:
- No PFP
- No F&G
- No De-Pressurization
- Poor Firewater system
## Consequence Analysis Results

<table>
<thead>
<tr>
<th>Event</th>
<th>Threshold</th>
<th>Impact Distance</th>
<th># Fatality</th>
</tr>
</thead>
<tbody>
<tr>
<td>BLEVE Fireball Distances (m) at 1 m above Ground</td>
<td>1000 tdu</td>
<td>196 m</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2000 tdu</td>
<td>123 m</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3200 tdu (%100 Fatality)</td>
<td>72 m</td>
<td>5*</td>
</tr>
<tr>
<td>Jet Fire</td>
<td>35 kW/m² (%100 Fatality)</td>
<td>46 m</td>
<td>5*</td>
</tr>
<tr>
<td>Overpressure</td>
<td>5 psig (%100 Fatality indoor)</td>
<td>64 m</td>
<td>5*</td>
</tr>
<tr>
<td>Overpressure</td>
<td>7.5 psig (%50 Fatality indoor)</td>
<td>51 m</td>
<td>2.5*</td>
</tr>
</tbody>
</table>

* Assume 10 workers/operators are working outdoor and 5 operators inside the building.
# Risk Plotting

<table>
<thead>
<tr>
<th>N</th>
<th>&lt;10⁻⁶</th>
<th>10⁻⁶ &lt; to &lt;10⁻⁴ avg. 10⁻⁵</th>
<th>10⁻⁴ &lt; to &lt;10⁻³ avg. 10⁻⁴</th>
<th>10⁻³ &lt; to &lt;10⁻² avg. 10⁻³</th>
<th>10⁻² &lt; avg. 10⁻²</th>
</tr>
</thead>
<tbody>
<tr>
<td>N= 50+</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N= 10 to 50</td>
<td></td>
<td></td>
<td>BLEVE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N= 3 to 10</td>
<td></td>
<td>Jet Fire</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N= 1 to 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medical Aid</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Defensive Fire Protection Design Options

1. Emergency Systems (ESD, F&G, Depressurization)
2. Passive Fire Protection
3. Emergency systems + Active Fire Protection
4. Emergency system + Passive Fire Protection
## Improvements

<table>
<thead>
<tr>
<th>Improvement</th>
<th>Improvement</th>
<th>Existing PFD</th>
<th>Improved PFD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Firewater Diesel Pump</td>
<td></td>
<td>0.12</td>
<td>0.065</td>
</tr>
<tr>
<td>Deluge Valve tests Interval</td>
<td>From 3yrs to 6 months</td>
<td>0.015</td>
<td>0.0063</td>
</tr>
<tr>
<td>Detection system Valves tests Interval</td>
<td>From 1 yr to 6 months</td>
<td>4.95 x 10^-3</td>
<td>2.5 x 10^-3</td>
</tr>
<tr>
<td>ESDV test interval</td>
<td>From 1 yr to 6 months</td>
<td>2.9 x 10^-3</td>
<td>1.5 x 10^-3</td>
</tr>
</tbody>
</table>
## Improve Risk Frequency

<table>
<thead>
<tr>
<th>Event</th>
<th>1 Detection/ ESD/ Depress.</th>
<th>2 Passive Fire Protection</th>
<th>3 Improved F&amp;G/ESD/ Depress. &amp; AFP</th>
<th>4 Improved F&amp;G/ESD/ Depress. &amp; PFP</th>
</tr>
</thead>
<tbody>
<tr>
<td>VCE</td>
<td>2.9 x 10^{-6}</td>
<td>5.83 x 10^{-5}</td>
<td>1.36 x 10^{-6}</td>
<td>1.34 x 10^{-6}</td>
</tr>
<tr>
<td>BLEVE</td>
<td>2.9 x 10^{-6}</td>
<td>5.83 x 10^{-8}</td>
<td>7.15 x 10^{-7}</td>
<td>1.34 x 10^{-9}</td>
</tr>
<tr>
<td>Jet Fire</td>
<td>N/A</td>
<td>5.82 x 10^{-5}</td>
<td>6.2 x 10^{-7}</td>
<td>1.33 x 10^{-6}</td>
</tr>
<tr>
<td>Controlled Fire</td>
<td>1.11 x 10^{-4}</td>
<td>N/A</td>
<td>1.14 x 10^{-4}</td>
<td>1.14 x 10^{-4}</td>
</tr>
<tr>
<td>BLEVE Event Frequency</td>
<td>2.9 x 10^{-6}</td>
<td>5.83 x 10^{-8}</td>
<td>7.15 x 10^{-7}</td>
<td>1.34 x 10^{-9}</td>
</tr>
</tbody>
</table>
# Improved Risk Plotting

<table>
<thead>
<tr>
<th>N= 50+</th>
<th>10^{-6}</th>
<th>10^{-6} &lt; to 10^{-4}</th>
<th>10^{-4} &lt; to 10^{-3}</th>
<th>10^{-3} &lt; to 10^{-2}</th>
<th>10^{-2} &lt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>avg. 10^{-5}</td>
<td>avg. 10^{-4}</td>
<td>avg. 10^{-3}</td>
<td>avg. 10^{-2}</td>
<td></td>
</tr>
<tr>
<td>N= 10 to 50</td>
<td>Option 2,3 &amp; 4</td>
<td>Option 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N= 3 to 10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N= 1 to 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medical Aid</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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What would change the results

- Risk matrix structure
- Type of Fire
- Population Distribution
- Spacing, siting, building type
- Equipment arrangement
- Mechanical Integrity Program
Thank you

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