Fire Protection Analysis

Warren J. Baker Center for Science and Mathematics
San Luis Obispo, California

Prepared and presented by Blake Johnson
Winter Quarter 2015
Overview

- Project Building Information
- Prescriptive Analysis
  - Structural Fire Protection Analysis
  - Egress Analysis
  - Fire Suppression System Analysis
  - Fire Alarm and Detection System Analysis
- Performance-Based Analysis
  - Fire Scenario Selection
  - Atrium Analysis
Project Building Information

- Warren J. Baker Center for Science and Mathematics
- Building 180 on Cal Poly SLO campus
- 6-story, ~189,000 ft² area, with lecture halls, labs, offices, study spaces
- Accommodates ~1650 students in classrooms and labs
Project Building Information

- Type I-B construction
- Occupancy primarily B, some A, H, and S
- Total occupant load of 2906 persons
- 108 ft height, non-high-rise
- Fully sprinklered
- 5-story atrium
Structural Fire Protection Analysis

• Structural Summary
• Fire Resistance Requirements
• Structural Fire Protection (IBC)
Structural Summary

- Steel frame construction
  - W-section beams, girders, and columns
  - Moment frame
  - Metal deck with LW concrete fill
  - HSS used in vertical shafts
- 16" thick reinforced concrete retaining walls on levels 1 and 2
Fire Resistance Requirements

- Fire resistance ratings (Table 601)
  - Members supporting roof only use lower rating
  - S-1 roof must be 1-hour
  - Separation distance over 30 ft (Table 602 not used)

- Separation of occupancies (Table 508.4)
  - B and all, except itself and S-1, by 1-hour
  - S-1 and S-2 by 1-hour
  - S-2 and H-3 by 1-hour

### Structural Element Hourly Rating

<table>
<thead>
<tr>
<th>Structural Element</th>
<th>Hourly Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structural Frame</td>
<td>2 or 1</td>
</tr>
<tr>
<td>Bearing walls Exterior</td>
<td>2</td>
</tr>
<tr>
<td>Bearing walls Interior</td>
<td>2 or 1</td>
</tr>
<tr>
<td>Non-bearing walls</td>
<td>0</td>
</tr>
<tr>
<td>Floor</td>
<td>2</td>
</tr>
<tr>
<td>Roof</td>
<td>0 or 1</td>
</tr>
</tbody>
</table>

### Hourly Separation of Occupancies

<table>
<thead>
<tr>
<th></th>
<th>S-1</th>
<th>S-2</th>
<th>H-3</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>S-1</td>
<td>-</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>S-2</td>
<td>-</td>
<td>-</td>
<td>1</td>
</tr>
</tbody>
</table>
Structural Fire Protection

• W-shapes fireproofed with SFRM
  – W-shaped girders and beams fireproofed to UL Design No. 917
  – W-shaped columns fireproofed to UL Design No. X772
  – SFRM boxed with steel channels and gypsum wallboard
  – SFRM thickness listed in UL Design No.

• Floor deck rating from IBC (Table 721.2.2.1 and 721.2.2.1.3)
  – Effective slab thickness calculated to be 3.75"
  – Required thickness for LW concrete of 3.6" met for 2-hour rating

• RC retaining walls on levels 1 and 2 are well beyond the required 5" (Table 721.1(2)) to meet a 2-hour fire rating
Egress Analysis

• Occupancy
• Means of Egress
• Fire Rating
• Tenability
  (LSC)
Occupancy

- Mixed occupancy (6.1.14.2.2)
- A-3 most restrictive
- Plans IBC, but meet LSC with minor discrepancies
- Occupants are adult students and professors who are awake and alert
- Occupancy maps on following slides

<table>
<thead>
<tr>
<th>Group</th>
<th>Level</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>All</td>
<td>Atrium, Classrooms, Labs, Offices, Workspaces, others</td>
</tr>
<tr>
<td>A-3</td>
<td>1, 3, 4, 5, 6</td>
<td>Lecture Halls, Terraces</td>
</tr>
<tr>
<td>H-3</td>
<td>2</td>
<td>Hazardous</td>
</tr>
<tr>
<td>S</td>
<td>All</td>
<td>Storage</td>
</tr>
<tr>
<td>S-1</td>
<td>All</td>
<td>Mechanical</td>
</tr>
<tr>
<td>S-2</td>
<td>1</td>
<td>Electrical</td>
</tr>
</tbody>
</table>
Means of Egress

- Capacity designed with IBC load factors!
  - Stair 0.2 vs. 0.3 LSC
  - Door 0.15 vs. 0.2 LSC
- Still meets LSC

<table>
<thead>
<tr>
<th>Level</th>
<th>Component</th>
<th>Load (persons)</th>
<th>Factor (in/person)</th>
<th>Width (in)</th>
<th>Meets Required?</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Door Main</td>
<td>352</td>
<td>0.2</td>
<td>71</td>
<td>216</td>
</tr>
<tr>
<td>1</td>
<td>Door Back</td>
<td>352</td>
<td>0.2</td>
<td>71</td>
<td>96</td>
</tr>
<tr>
<td>1</td>
<td>Door 4</td>
<td>160</td>
<td>0.2</td>
<td>32</td>
<td>36</td>
</tr>
</tbody>
</table>
Means of Egress

- Number of exits OK (7.5.1.3)
- Common path of travel, dead end, and travel distances OK

<table>
<thead>
<tr>
<th>LSC Section and Distance</th>
<th>Assembly</th>
<th>Business</th>
<th>Storage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Common Path</td>
<td>12.2.5.1.2</td>
<td>38.2.5.3.1</td>
<td>42.2.5</td>
</tr>
<tr>
<td></td>
<td>20 or 75* ft</td>
<td>100 ft</td>
<td>100 ft</td>
</tr>
<tr>
<td>Dead End</td>
<td>12.2.5.1.3</td>
<td>38.2.5.2</td>
<td>42.2.5</td>
</tr>
<tr>
<td></td>
<td>20 ft</td>
<td>50 ft</td>
<td>100 ft</td>
</tr>
<tr>
<td>Travel Distance</td>
<td>12.2.6.2(1)</td>
<td>38.2.6.3</td>
<td>42.2.6</td>
</tr>
<tr>
<td></td>
<td>250 ft</td>
<td>300 ft</td>
<td>400 ft</td>
</tr>
</tbody>
</table>
Means of Egress

- Exit signage OK, but could be reduced with 7.10
- Estimated total evacuation time calculated using NFPA Fire Protection Handbook Chapter 4-2
  - Queuing assumed
  - Travel speed down stairs: 105 ft/min
  - Travel speed through atrium (Stair 3): 235 ft/min
Means of Egress

- Estimated total evacuation time is about 13 minutes
- Pre-movement (delay) time not accounted for in calculation
  - Delay time can be estimated from SFPE Handbook Table 3-12.2
  - Consider as mid-rise office building (warm day) – delay time average 36 seconds
- Total evacuation time about 13.5 minutes
Fire Rating

- Stair enclosures (7.1.3.2.1) and interior finish (__.3.3)
- Interior finish reduced by one step (10.2.8)
  - Controlled by Assembly
  - Stairways Class A or B
  - Elsewhere Class A, B, or C
  - Floor Class I or II or meets 10.2.7.2

<table>
<thead>
<tr>
<th>Stair #</th>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
<th>Level 4</th>
<th>Level 5</th>
<th>Level 6</th>
<th>Total</th>
<th>Fire Resistance Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>3</td>
<td>1-hour 2-hour</td>
</tr>
<tr>
<td>3</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td>5</td>
<td>2-hour 2-hour</td>
</tr>
<tr>
<td>4</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td>4</td>
<td>2-hour 2-hour</td>
</tr>
<tr>
<td>5</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td>1-hour 2-hour</td>
</tr>
</tbody>
</table>
Tenability

- Any occupant not intimate with ignition shall not be exposed to untenable conditions (5.2.2)
- Smoke/visibility controls tenability
- Based on fire scenarios
- Especially important in atrium
Fire Suppression System Analysis

- Occupancy
- Water Supply
- Fire Suppression System (NFPA 13)
Occupancy

- Mostly light hazard (5.2)
- Some ordinary hazard group 1 (5.3)
  - Labs, storage, and utility
  - Storage incidental, classified as miscellaneous (3.9.1.1.8)
  - Commodities can be Class I or II (Table 13.2.1)
- Sprinkler design area 1500 ft² and density meets design curves in Figure 11.2.3.1.1
  - Light: 0.10 gpm/ft²
  - Ordinary: 0.15 gpm/ft²
- Hose stream allowance meets Table 11.2.3.1.2
  - Light: 100 gpm
  - Ordinary: 100 gpm inside, 150 gpm outside, for 250 gpm total
Water Supply

- Water supply is city water
  - Static pressure: 60 psi
  - Residual pressure: 55 psi
  - Flow rate: 914 gpm
- Highest pressure demand at base of riser is 168 psi
- Adequate flow, poor pressure – pump required
- Fire pump in-line, rated at 750 gpm, 113 psi, 58.1 HP, efficiency 85.3%

FLOW TEST SUMMARY

<table>
<thead>
<tr>
<th>STATIC PSI</th>
<th>RESIDUAL PSI</th>
<th>PITOT PSI</th>
<th>ORIFICE DIAMETER</th>
<th>COEFFICIENT OF DISCHARGE</th>
<th>GPM</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>60</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>55</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>35</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

DATE: 8-19-2011
LOCATION: N. POLY VIEW DRIVE
BY WHO: FLUID RESOURCE MANAGEMENT, INC.

ADJUSTED FLOW
10% REDUCTION

<table>
<thead>
<tr>
<th>STATIC PSI</th>
<th>RESIDUAL PSI</th>
<th>GPM</th>
</tr>
</thead>
<tbody>
<tr>
<td>54</td>
<td>49</td>
<td>914</td>
</tr>
</tbody>
</table>

STATIC & RESIDUAL TAKEN FROM HYD. # 63
FLOW TAKEN FROM HYD. # 64
Fire Suppression System

- Wet pipe system (7.1)
- Most pipes concealed
- Standpipes and riser concealed in stairways
- Sprinklers mostly pendant type, some upright type
  - Quick response
  - K-factor 5.6
- System supported by TOLCO seismic braces

<table>
<thead>
<tr>
<th>Stair #</th>
<th>Type</th>
<th>Pipe Size</th>
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<tbody>
<tr>
<td>1</td>
<td>Standpipe</td>
<td>6” Schedule 10</td>
</tr>
<tr>
<td>3</td>
<td>Riser</td>
<td>6” Schedule 10</td>
</tr>
<tr>
<td>4</td>
<td>Standpipe</td>
<td>4” Schedule 10</td>
</tr>
<tr>
<td>5</td>
<td>Standpipe</td>
<td>4” Schedule 10</td>
</tr>
<tr>
<td>-</td>
<td>Cross mains</td>
<td>2½” to 3” Schedule 10</td>
</tr>
<tr>
<td>-</td>
<td>Branch lines</td>
<td>1” to 1¼” Schedule 10</td>
</tr>
</tbody>
</table>

Seismic design category: D
Soil profile: Type B
Spectral response accelerations:
- $S_s = 1.26$
- $S_1 = 0.481$
Seismic coefficient: $C_p = 0.61$
Fire Alarm and Detection System Analysis

• Fire Alarm System
• Fire Detection System
  (NFPA 72)
Fire Alarm System

- Fire alarm with in-building fire emergency voice alarm communication system (EVACS)
- No mass notification system (MNS)
- Fire alarm control panel (FACP) located in main electrical/transformer room (room122) on level 1
  - FACP is Honeywell Notifier, model # NFS2-640
- Fire alarm terminal cabinets (FATC) on levels 2, 3, 4, and 5 located in utility spaces
Fire Alarm System

- 73 strobes
- 13 speakers (7 are weather proof)
- 165 speaker/strobes
- 29 trouble monitors (non-alarm points)
- 7 workflow alarm devices
- At least one fire alarm device located in each space
Fire Alarm System

- Audible devices must have a sound level at least 15 dB above the average ambient sound level (18.4.3)
  - Average ambient sound level is 55 dBA
  - Minimum speaker sound level is 70 dBA
- Device sound level in dBA determined from wattage and model number given on plans
  - Horns meet 70 dBA after 40' of sound loss
  - All points in every space within 40' of a horn so audible requirements met
- Candela ratings for strobes given on plans
  - Candela ratings adequate to cover area (Table 18.5.5.4.1(a)) of all rooms
  - Visible signaling requirements (18.5) met for all rooms
Fire Alarm System

- EVACS (24.4.2)
  - 1 voice alarm channel
  - 172 speakers
  - 9 speaker circuits
- Amplification and sound-processing equipment located at FATC locations
- Paging microphone station is at the fire alarm control unit (FACU) in room 122 (24.4.2.5)
Fire Detection System

- Requirements NFPA 72, placements IBC
- Smoke detection system (17.7)
  - Photoelectric smoke detectors (17.7.3.2)
  - Photoelectric duct detectors (17.7.5)
  - Beam smoke detectors (17.7.3.7)
- Manual pull stations (IBC 907.4.2)
- Sprinklers
Fire Scenario Selection

• Fire Risk
• Example Scenario
Fire Risk

- LSC 5.5.3.6 – Design fire scenario 1
- Probabilistic approach based on statistical data of buildings with similar uses
- NFPA report “Structure Fire in Educational Properties” (Richard Campbell, 2013)
  - 700 fires involving college classroom buildings and adult education centers per year
  - Data from 2007-2011

<table>
<thead>
<tr>
<th>Cause</th>
<th>Fires (%)</th>
<th>Damage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooking equipment</td>
<td>51</td>
<td>2</td>
</tr>
<tr>
<td>Intentional</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Heating equipment</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Smoking materials</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Electrical distribution &amp; lighting equipment</td>
<td>5</td>
<td>18</td>
</tr>
</tbody>
</table>
Fire Risk

<table>
<thead>
<tr>
<th>Area of Origin</th>
<th>Fires (%)</th>
<th>Injuries (%)</th>
<th>Damage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooking Area</td>
<td>2</td>
<td>16</td>
<td>2</td>
</tr>
<tr>
<td>Bathroom</td>
<td>2</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Laboratory</td>
<td>3</td>
<td>44</td>
<td>18</td>
</tr>
<tr>
<td>Hallway or corridor</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Office</td>
<td>2</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>Duct for HVAC</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Machinery room</td>
<td>2</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Small assembly area (&lt; 100 persons)</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Terrace</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

- **Cooking appliance** fire in a **cooking area**
- **Intentional** fire in a **laboratory**
- **Heating/electrical equipment** fire in an **office**
Example Scenario

- Intentional laboratory fire
  - Fuel: Flammable laboratory chemicals
  - Cause: Experiment gone awry
- t-squared ultrafast fire
Example Scenario

- DETACT model can be used
  - No smoke detectors, sprinklers only
  - Spaced at 10 ft, ceiling height 10' 6"
  - Activation temperature 68.3 °C – RTI 266 m$^{1/2}$s$^{1/2}$
- Activation time is 115 seconds, at an HRR of 2500 kW
Atrium Analysis

• Atrium Information
  • Tenability
  • CFAST
  • FDS
Atrium Information

- 5-story atrium on levels 2 to 6
- Connects East and West wings of building
- Offices connect to atrium
  - Through lobbies on levels 2 and 3
  - Directly on levels 4, 5, and 6
- Convenience stairway not part of the primary means of egress
- Stair 3 exit access and discharge passing through atrium allowed (LSC 8.6.7(2))
- Offices directly connected must be protected by a 1-hour fire barrier OR engineering analysis required (LSC 8.6.7)
  - NOT protected by a 1-hour fire barrier
  - Engineering analysis must be performed to meet LSC!

[Image of atrium]
Tenability

• Primary tenability concern is to keep smoke layer 6 feet above floor
  – Smoke control system in atrium is passive natural ventilation
  – Fires originating in or adjacent to the atrium

• Available safe egress time (ASET) must exceed the required safe egress time (RSET), ASET > RSET
Tenability

- ASET determined by models
- RSET calculated by hand
  - (1) From furthest office through stair 3 to exit
  - (2) From furthest office to West hallway (exits atrium)
  - EVACS can be used to route occupants based on where fire is detected
  - Factor of safety, typically 1.5, should be considered when comparing ASET and RSET

<table>
<thead>
<tr>
<th>(1) RSET Action</th>
<th>Time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delay</td>
<td>36</td>
</tr>
<tr>
<td>Travel</td>
<td></td>
</tr>
<tr>
<td>to exit stair 3</td>
<td>40</td>
</tr>
<tr>
<td>from level 6</td>
<td>114</td>
</tr>
<tr>
<td>to level G2</td>
<td></td>
</tr>
<tr>
<td>to exit door</td>
<td>16</td>
</tr>
<tr>
<td>TOTAL</td>
<td>206</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>(2) RSET Action</th>
<th>Time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delay</td>
<td>36</td>
</tr>
<tr>
<td>Travel to atrium exit door</td>
<td>40</td>
</tr>
<tr>
<td>TOTAL</td>
<td>76</td>
</tr>
</tbody>
</table>
CFAST

• Compartments based on area for each floor, East and West hallways, and floor-to-floor, vertical openings
• Smoke detectors positioned at zones between floors
  – Positioned to represent beam detectors
  – Smoke-temperature correlation (13 °C rise) as detection basis
• Natural ventilation
  – East/West hallway doors initially open and automatically close at time when fire detected
  – Ground level doors initially closed and automatically open at time when fire detected
• Two fire scenarios
  – Office fire adjacent to atrium that spills smoke into the atrium
  – Upholstered chair fire in atrium
CFAST

- Office fire
  - Fire: t-squared ultrafast 3500 kW (represents a 3-panel workstation)
  - Location: 6th floor office connected to atrium
  - Office door held open, fire far from single room sprinkler and ceiling duct vent
- Detection: Duct smoke detector at 30 s
CFAST

- ASET > RSET for all levels: design criterion met
- ASET ≥ 1.5 * RSET for levels 5 and 6
  - Margin of safety not met
  - EVACS should inform atrium occupants on levels 5 and 6 to use alternative exits at East/West ends of building

<table>
<thead>
<tr>
<th>Level</th>
<th>Smoke Layer Height at Detection (ft)</th>
<th>Time at Tenability Failure (s)</th>
<th>ASET (s)</th>
<th>RSET (1) (s)</th>
<th>ASET\rightarrow RSET (1)</th>
<th>RSET (2) (s)</th>
<th>ASET\rightarrow RSET (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>G2</td>
<td>11.3</td>
<td>260</td>
<td>230</td>
<td>52</td>
<td>4.42</td>
<td>52</td>
<td>4.42</td>
</tr>
<tr>
<td>3</td>
<td>10.3</td>
<td>180</td>
<td>150</td>
<td>121</td>
<td>1.90</td>
<td>76</td>
<td>1.97</td>
</tr>
<tr>
<td>4</td>
<td>10.6</td>
<td>320</td>
<td>290</td>
<td>149</td>
<td>1.54</td>
<td>76</td>
<td>3.82</td>
</tr>
<tr>
<td>5</td>
<td>10.5</td>
<td>370</td>
<td>340</td>
<td>178</td>
<td>1.29</td>
<td>76</td>
<td>4.47</td>
</tr>
<tr>
<td>6</td>
<td>10.5</td>
<td>600+</td>
<td>570+</td>
<td>206</td>
<td>1.12</td>
<td>76</td>
<td>7.5+</td>
</tr>
</tbody>
</table>
CFAST

- Upholstered chair fire, cotton fabric
  - Fire: t-squared medium 700 kW
  - Location: 1st floor center of atrium at wall
- Detection: Beam smoke detector at 130 s
CFAST

- Tenability failures on levels 3 through 5
- Checked with a more detailed analysis in FDS...

<table>
<thead>
<tr>
<th>Level</th>
<th>Smoke Layer Height at Detection (ft)</th>
<th>Time at Tenability Failure (s)</th>
<th>ASET (s)</th>
<th>RSET (1) (s)</th>
<th>ASET RSET (1)</th>
<th>RSET (2) (s)</th>
<th>ASET RSET (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>G2</td>
<td>7.1</td>
<td>600+</td>
<td>470+</td>
<td>52</td>
<td>9.0+</td>
<td>52</td>
<td>9.0+</td>
</tr>
<tr>
<td>3</td>
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<td>76</td>
<td>&lt; 1.0</td>
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<td>&lt; 1.0</td>
<td>76</td>
<td>1.58</td>
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</tbody>
</table>
FDS

- Same simplified geometry as CFAST
- Detection: Smoke detector at 85 s

![Diagram showing heat release rate and time](image_url)
FDS

<table>
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<tr>
<th>Level</th>
<th>Smoke Layer Height at Detection (ft)</th>
<th>Time at Tenability Failure (s)</th>
<th>ASET (s)</th>
<th>RSET (1) (s)</th>
<th>ASET ( \frac{1}{RSET} ) (1)</th>
<th>RSET (2) (s)</th>
<th>ASET ( \frac{1}{RSET} ) (2)</th>
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<td>-</td>
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<td>121</td>
<td>2.74</td>
<td>76</td>
<td>2.74</td>
</tr>
</tbody>
</table>

- Smoke layer does not form on levels 4 through 6
- ASET > RSET for all levels: design criterion met
FDS

• At level 3 tenability failure
THANK YOU!

Questions?