Aon Fire Protection Engineering

Kingdom Tower and other High-Rise Evacuation Strategies

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Safety Design in Buildings

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Learning Objectives

- Understand the challenges of Fire Safety in High Rise Buildings, particularly with regard to Means of Egress
- Introduction or review of Area of Refuge Concept and associated requirements
- Understand the advantages of partial or selective evacuation in high-rise buildings
- Consider elevator evacuation for super-tall high rise buildings

Summary

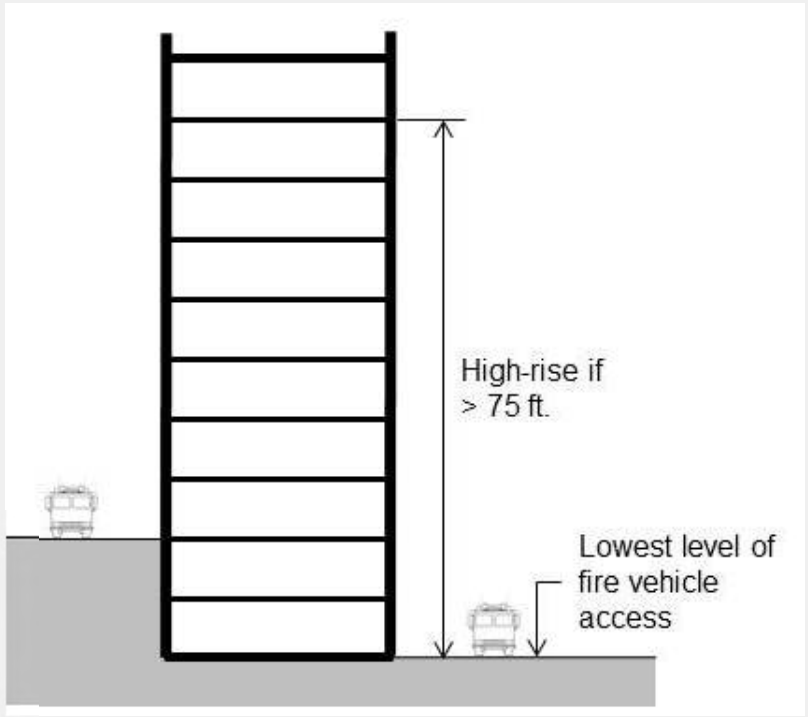
- Definition of High Rise Building
- Evolution of Current Practices
- Areas of Refuge
- Elevator Evacuation
- Contemporary Design: Kingdom Tower
- Operational Issues
- Conclusions

Speaker Bio

Shamim Rashid-Sumar, P.E., has over 13 years of experience in building and fire code consulting, fire dynamics, timed egress modeling, and performance based design. Since graduating with a B.S. in Fire Protection Engineering from the University of Maryland, she has performed fire protection evaluations, prepared fire and life safety strategies and design specifications, fire alarm system design, and other engineering analyses and studies. She has worked on a multitude of projects including government facilities, hospitals and medical centers, airport terminals, museums, high-rise buildings, hotels, shopping malls, and many special use facilities. She has recently joined Aon Fire Protection Engineering Corporation in Dubai as Director of Business Development and Project Manager.

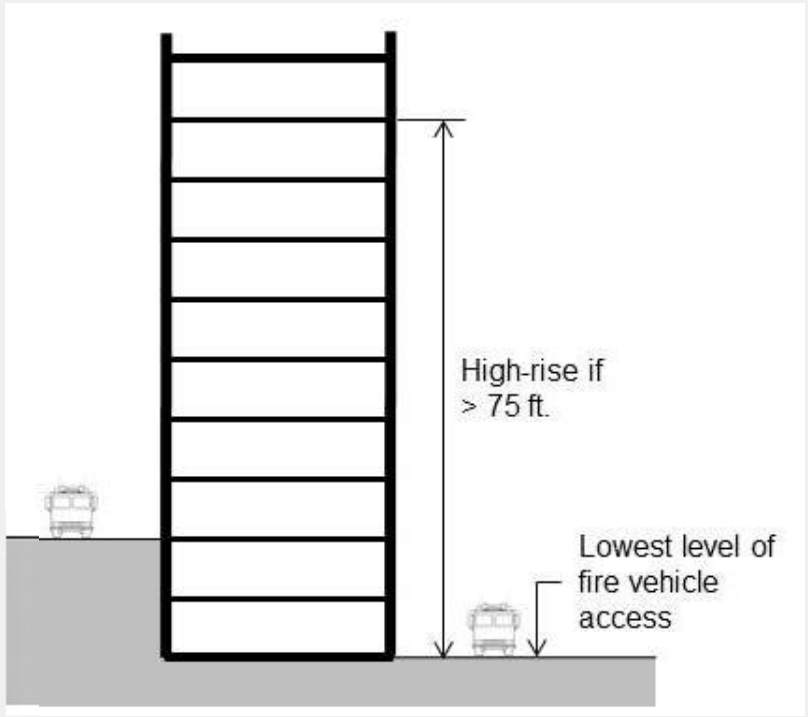
Ms. Rashid-Sumar was instrumental in establishing and currently serves as President of the UAE International Chapter of the Society of Fire Protection Engineers (SFPE). Prior to joining Aon FPE, she was responsible for establishing and managing RJA's Middle East office, where she most recently served as Vice President of Middle East Operations.

Definition



- **High Rise Building**
  - Occupied floor located more than 23 m (75 ft) above the lowest level of fire department vehicle access
- **Super Tall Building**
  - Considered more than 128 m (420 ft) tall

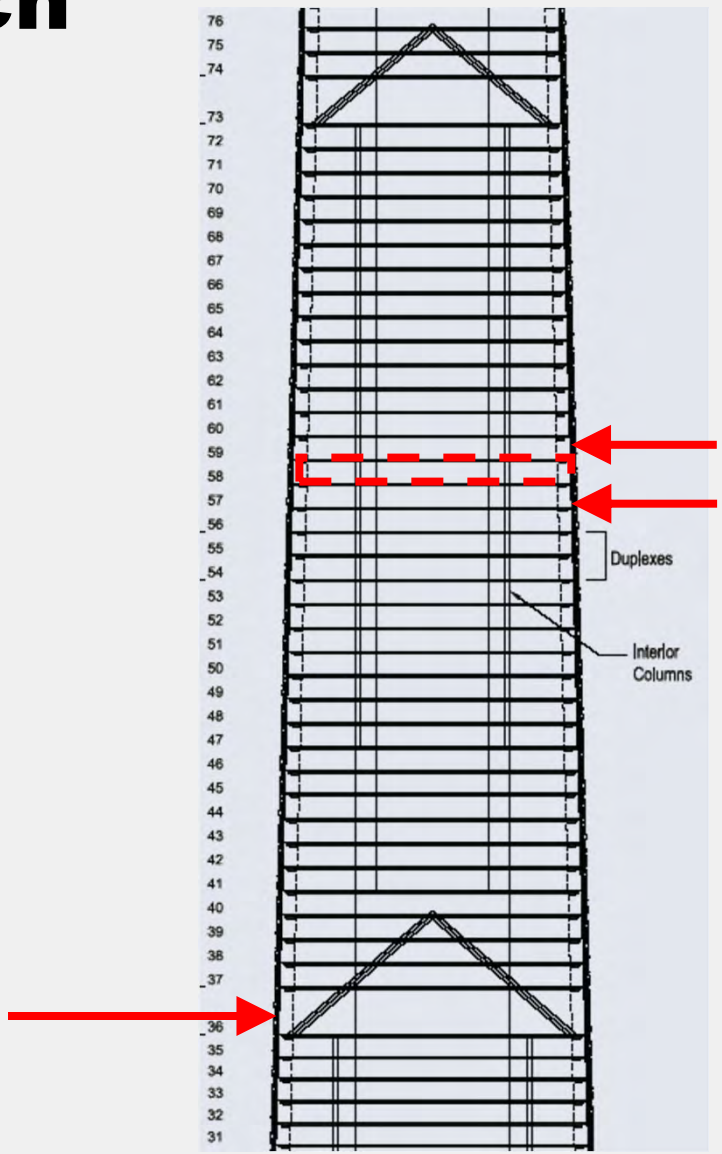
Challenges



- Large numbers of building occupants are located far above street level. Occupants cannot all be evacuated to grade in a timely manner.
- Because of the distance involved in reaching upper floors, the primary means of vertical circulation during normal conditions is by means of elevators.
- Many public utilities must be supplemented by building systems to provide adequate reliable services to the building.

Approach

- Control fire growth
- Protect occupants in place
  - Only selective evacuation of building occupants



Considerations

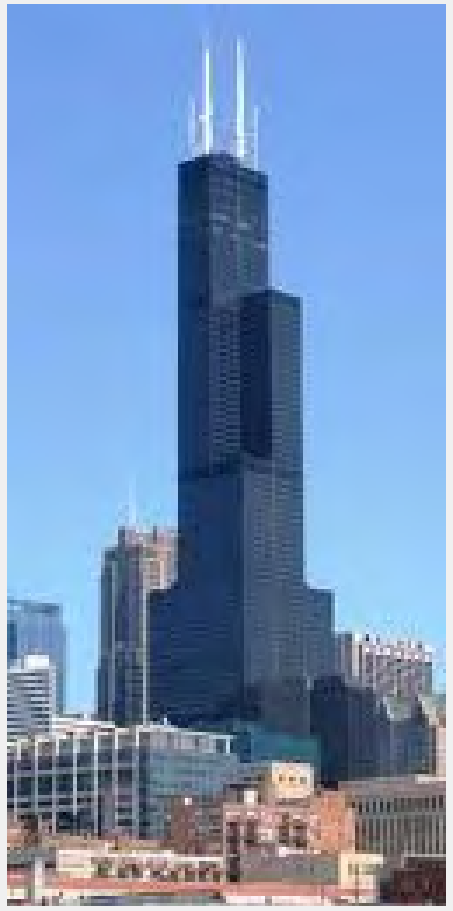
- Occupants of the building must be protected from the effects of a fire in the building primarily by controlling fire growth and limiting fire and smoke spread to a single fire-prevention zone.
- Fire fighting operations must be conducted primarily from inside the building, often times in locations extremely remote from fire service apparatus and ground support.
  - Fire fighting support systems must be built into the building design.
- Building must accommodate communication of emergency instructions to building occupants and communications between fire service personnel.
- Building occupants must be moved away from danger utilizing protected exit stairs leading to the exterior of the building.

Evolution of Current Practices

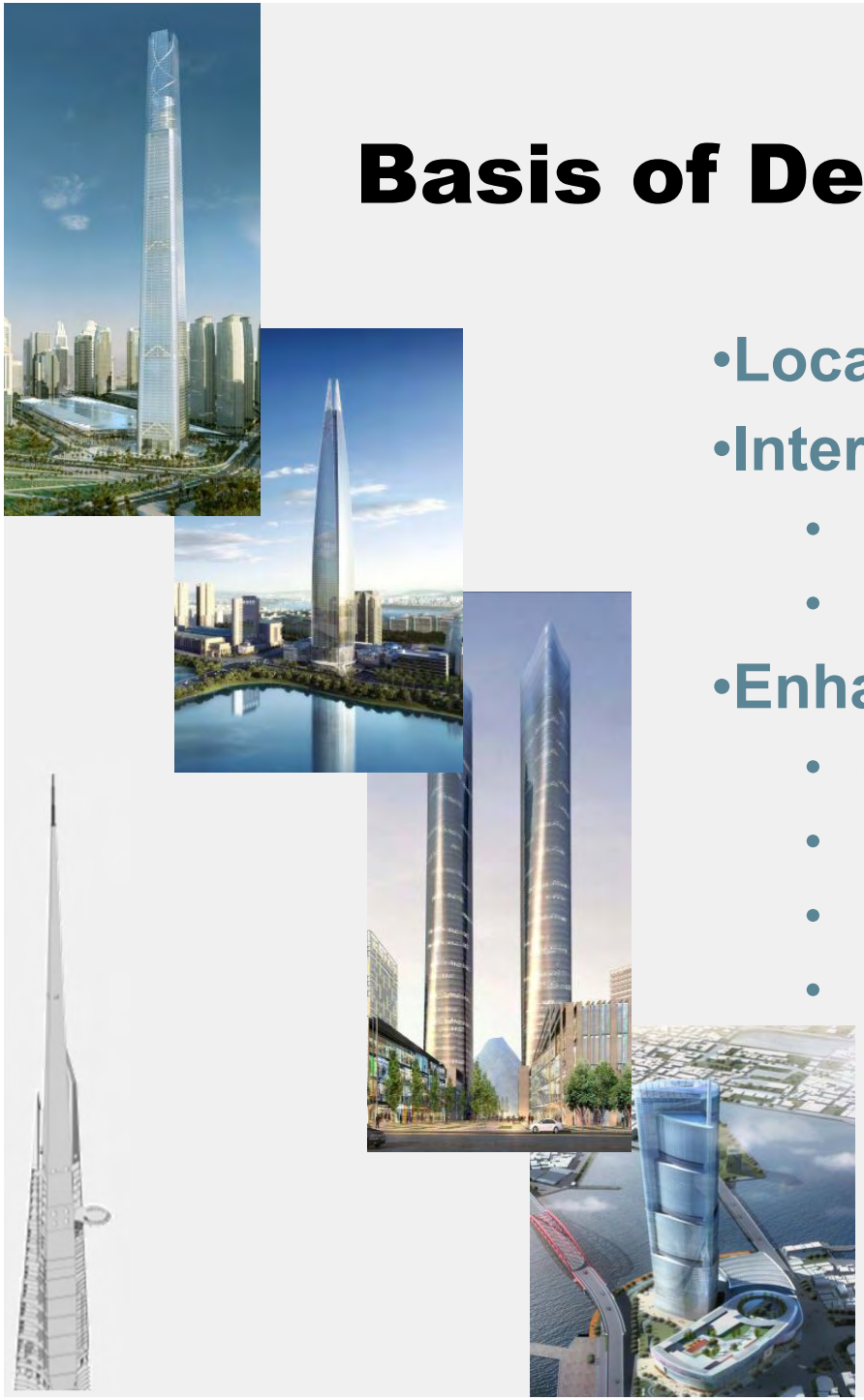
Post-1945 Expansion of High Rise Construction in US "Model Codes" Add Specific Provisions for High Rises 1975

Chicago Building Code- High Rise Chapter 13:

- Automatic Sprinklers
- Standpipes
- Occupant and Fire Dept. Voice Communications
- Stairway Unlocking



Basis of Design Approach



- Local Codes – To the Extent Feasible
- International Standards
  - International Building Code
  - NFPA
- Enhancements
  - Structural Fire Resistance
  - Refuge Areas
  - Elevator Evacuation
  - Fire Protection Water Supply

Basis of Design- Why IBC & NFPA?

- Consensus Standards developed by Design Community and Fire Service
- Adopted Locally – Tailored to Local Norms
- Updated Every Three Years to Reflect Application Experience
- Recognized World Wide

Fire Safety Concepts Tree – Areas of Refuge

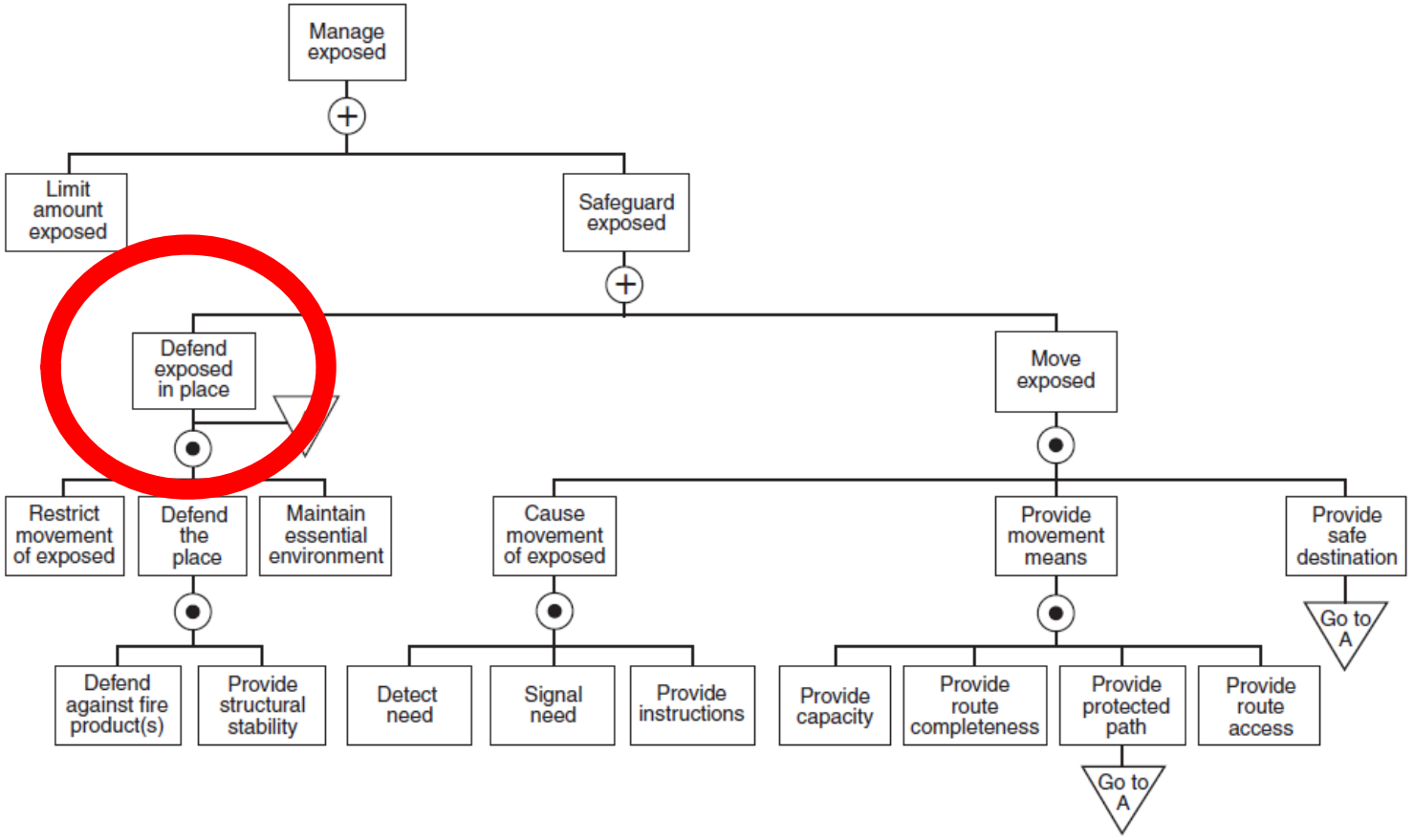
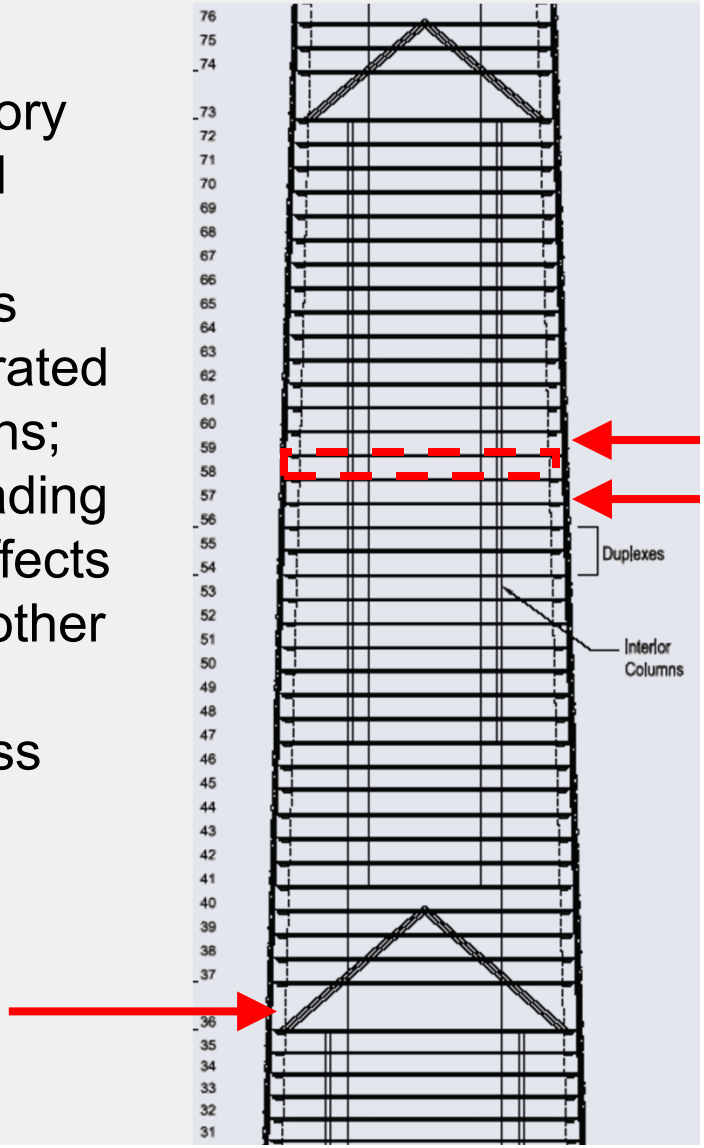


FIGURE 4.5.2.1 "Manage Exposed" Branch of Fire Safety Concepts Tree.

Courtesy NFPA 550

Phased Evacuation with Refuge Floors

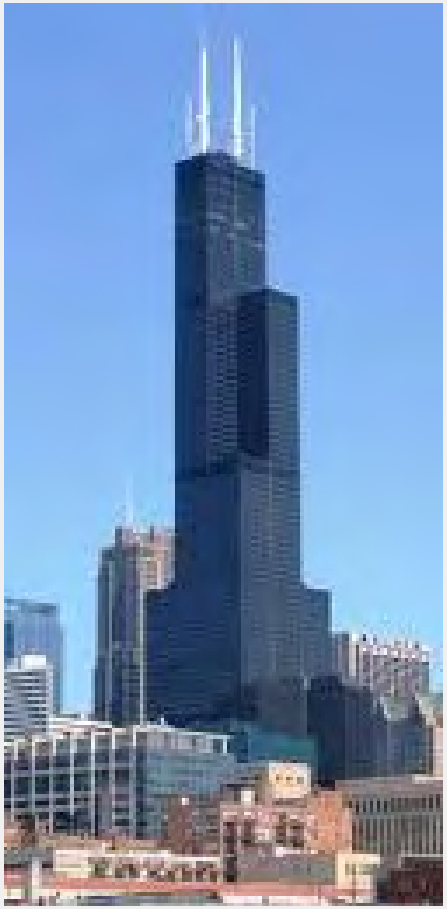
Area of Refuge. An area that is either (1) a story in a building where the building is protected throughout by an approved, supervised automatic sprinkler system and has not less than two accessible rooms or spaces separated from each other by smoke-resisting partitions; or (2) a space located in a path of travel leading to a public way that is protected from the effects of fire, either by means of separation from other spaces in the same building or by virtue of location, thereby permitting a delay in egress travel from any level.



Refuge Floors

U.S. High Rise Design 1970's and 80's

- Active Suppression to Control Fire Growth
- Fire Rated Building Structure
- Each Floor is an Area of Refuge
- Evacuation Sequence – Fire Floor, 2 Above, 1 Below – Evacuate "4 Floors Down"



Impetus for Refuge Area Discussion

- CTBUH Fire Safety Working Group
  - Experience with many tall, super tall buildings
  - Experiences in Asia, Europe, Middle East & North America
- Process of critical thinking, questioning
  - Focus primarily on refuge floors
  - Efficient ?
  - Sustainable design ?
  - How effective for life safety ?
- Better dialog and understanding of issues, concerns and reasons to consider implementation and refuge area options

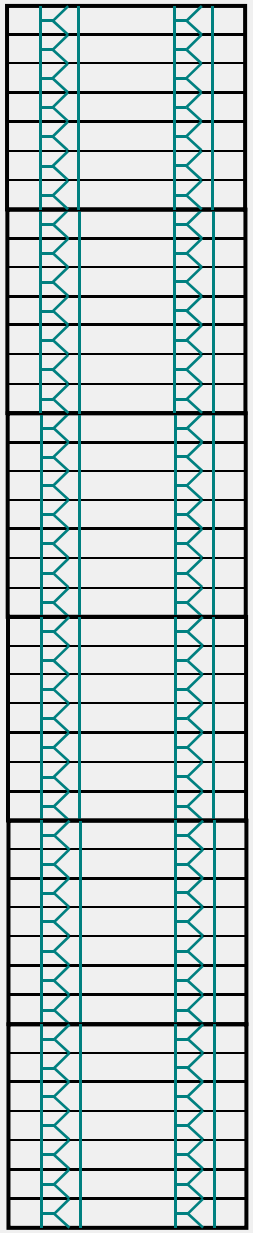
Refuge Spaces – Reasoning

- Taller means longer evacuation (1-3 hours)
- Descent on stairs physically demanding for some
- Stairs not conducive for
  - Mobility impaired occupants
  - Health impaired occupants
  - Temporary conditions – pregnancy, broken limb
- Total evacuation – not desirable feasible
- Stairs – smoke contamination even if pressurized when multiple doors open
- Fire brigade operations – stair egress conflicts, smoke entry to stair

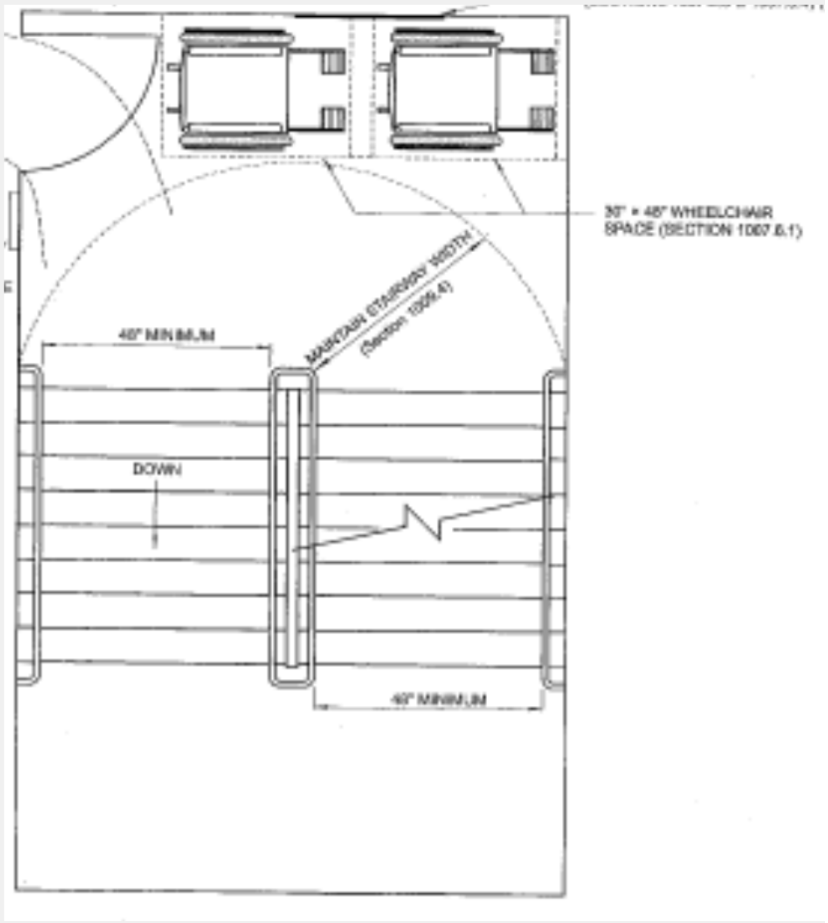
Providing Refuge – Two Methods

- Dispersed Approach
  - Developed out of need to address people with disabilities
  - Implementation in Europe, North America, Middle East
  - Options
    - All Floors a Refuge area in fully sprinkler buildings
    - Dedicated areas of refuge on each floor
    - Horizontal exits
    - Ramps to grade

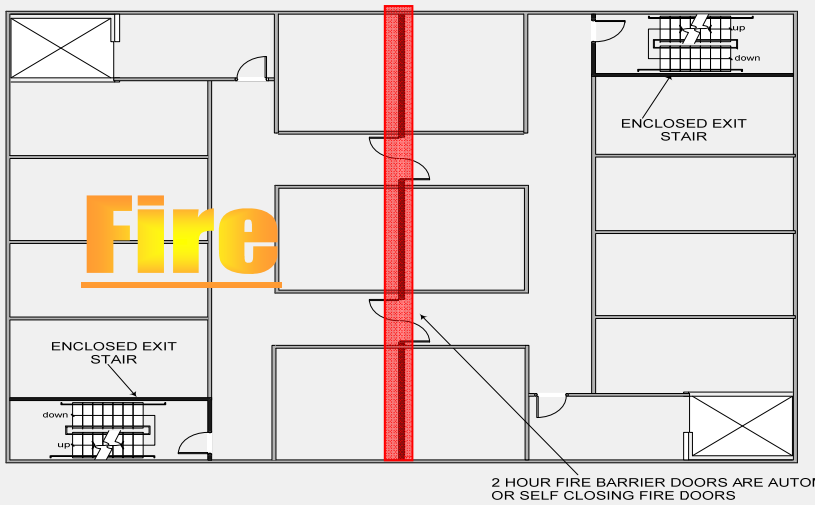
Dispersed Approach



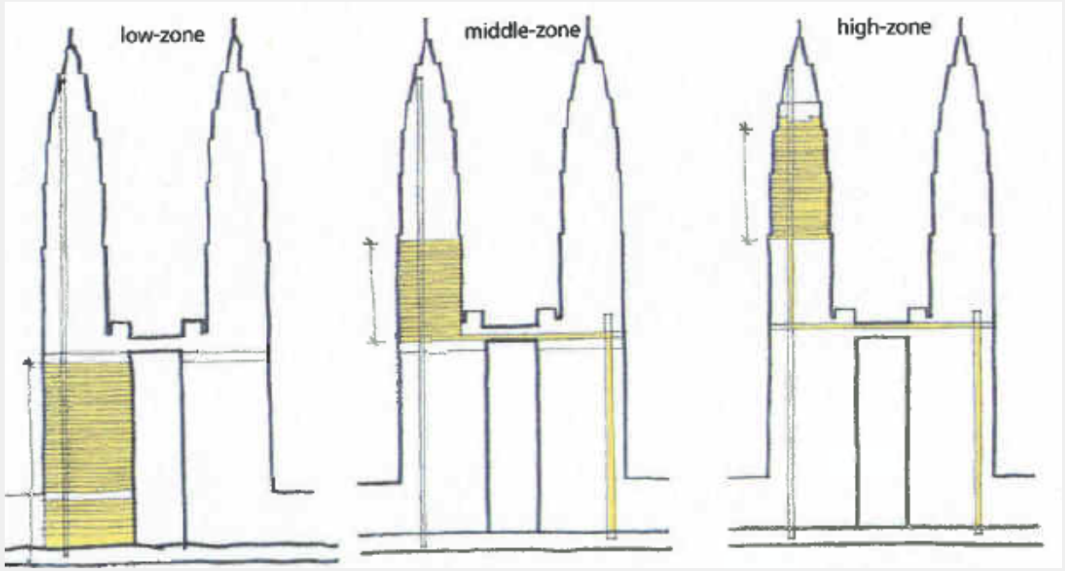
Each floor a refuge area when a supervised sprinkler system installed through entire building



Horizontal Exits\Bridges



2009, Pinnacle @ Duxton, Singapore, ARCStudios



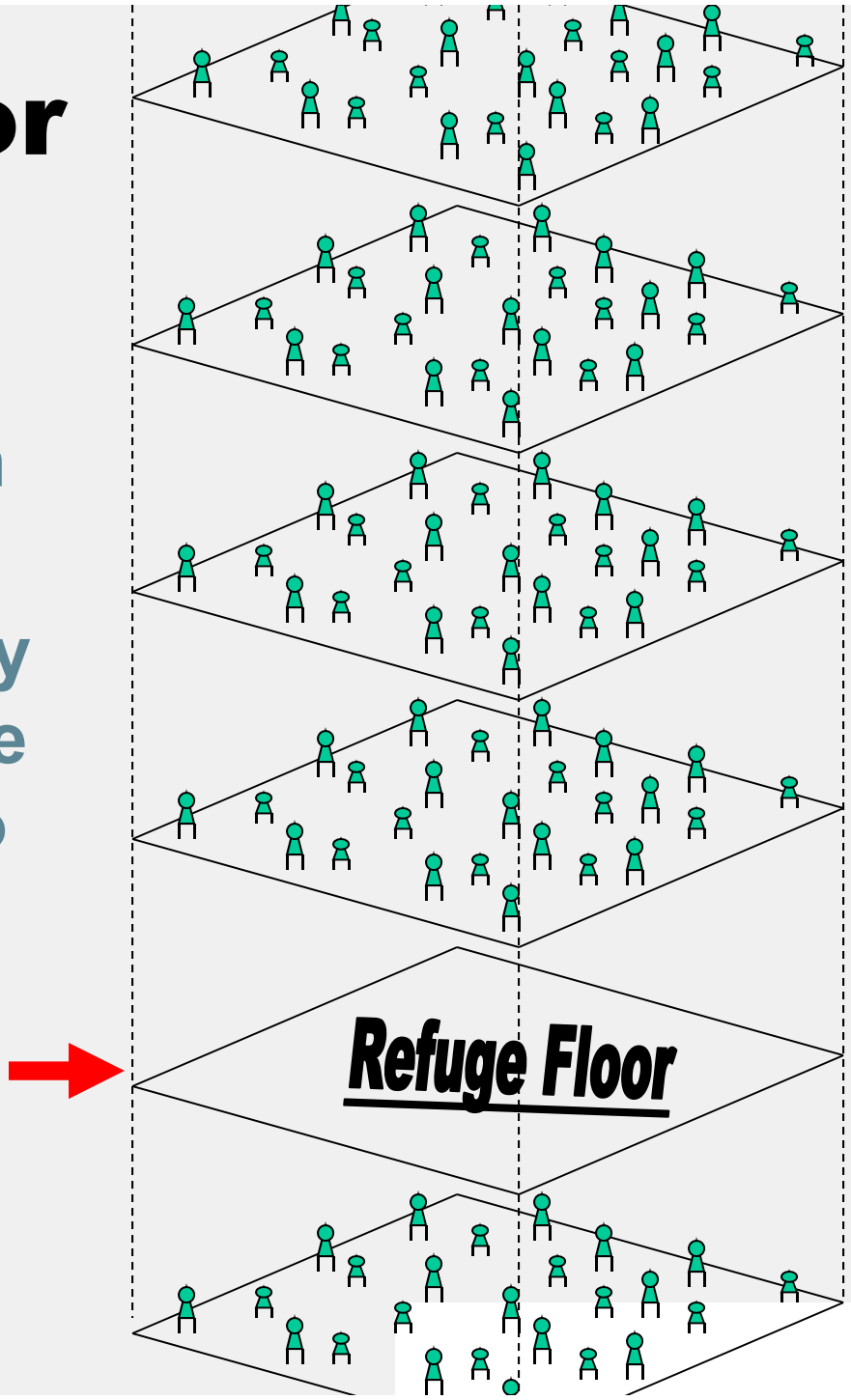
Petronas Diagram by Wood, Parry-Davis

Providing Refuge – Two Methods

- Consolidated Approach
  - Outcome of Asian fires in 1990's, including Hong Kong's Garland building
  - Gather occupants onto a few refuge floors
    - Pause during evacuation process
    - Assumed safe holding area, stay in refuge area and await further instructions
    - Location – one refuge floor every 15, 20, 25 floors (China, Korea, Hong Kong, Singapore)
    - India – one every 7 floors
  - Common feature is interruption of stairway at refuge floor

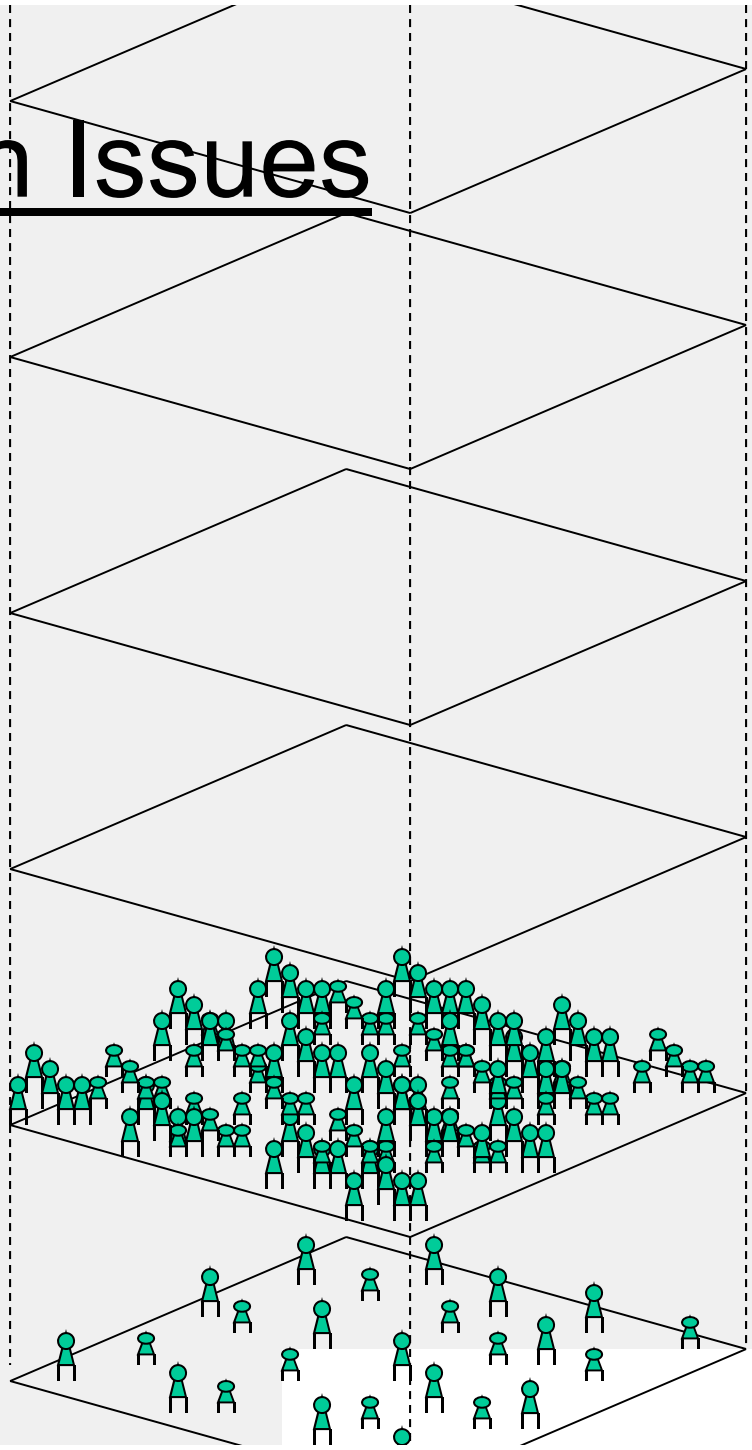
Refuge Floor Concept

- Dedicate an entire floor or large portion of a floor
- During an emergency move several or zone of occupied floors to the refuge floor



Refuge Floor Design Issues

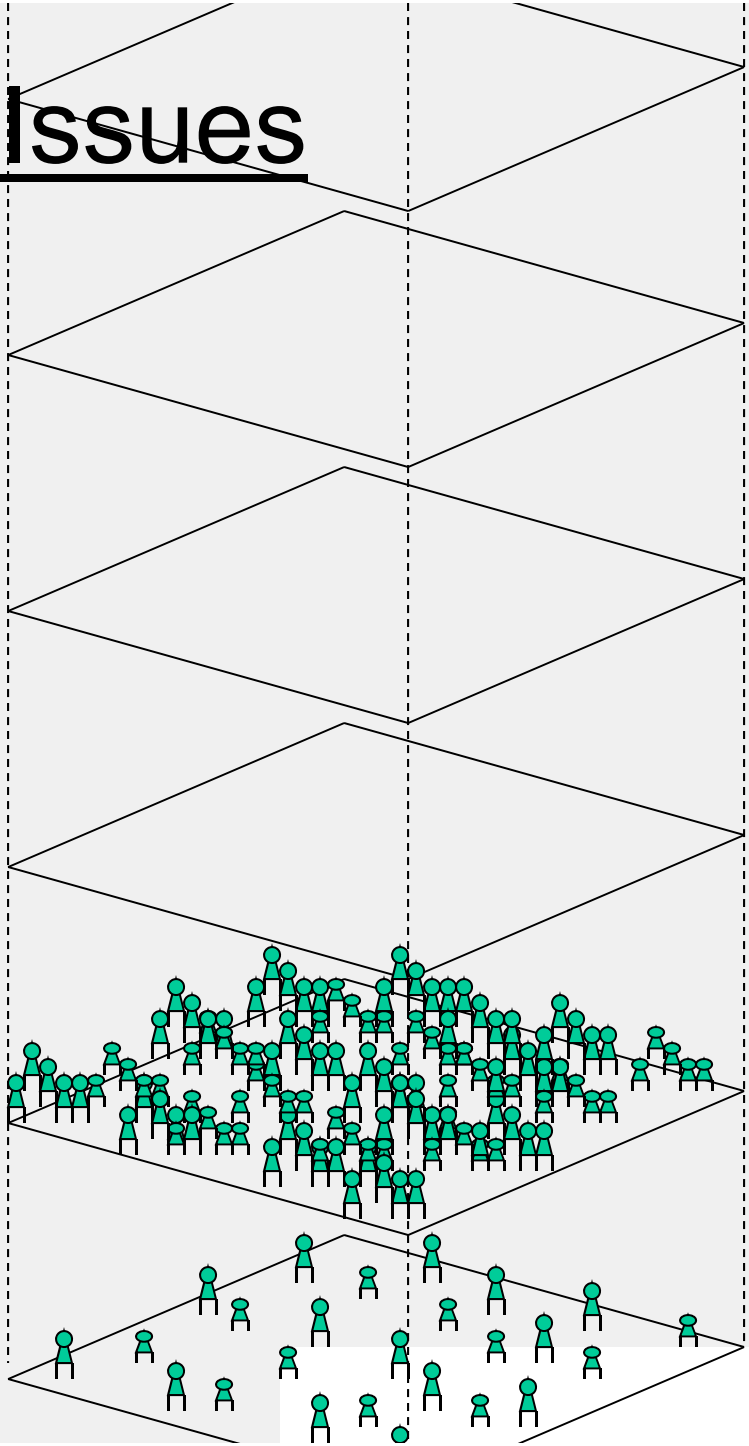
- Toilets & drinking water
- Seating facilities or standing room
- Emergency power for lighting, floor amenities
- Protection of floor from increasing fire spread
- Ventilation/HVAC design



Refuge Floor Safety Issues

- Designs using natural ventilation potential for smoke contamination
  - Kwok et al 2000
  - Cheng 2006
  - Chow & Chow 2009
- HVAC system functions
  - Adequate fresh air
  - Pressurization to keep floor clear of smoke
  - Air temperature comfort
- Over crowding
- Protection of floor from increasing fire spread

Large assembly of people, but only limited stairs



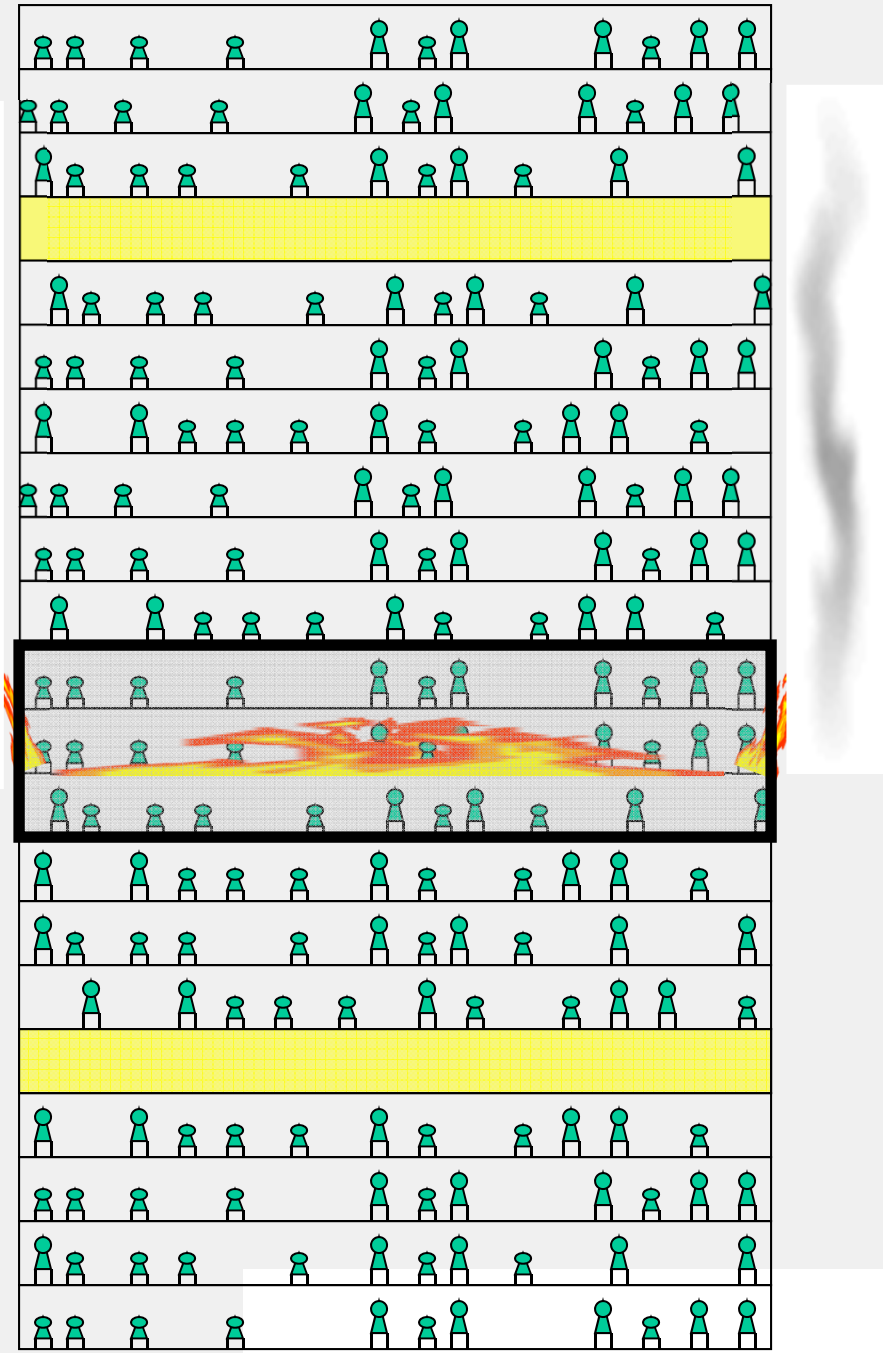
Refuge Floor Cost Issues

- Additional construction time to add floors
- Cleaning, HVAC costs for normally empty space
- Loss of efficiency/impact on leasing, usability for multi-floor tenants
- Property tax issues
- Loss of zoning potential (FAR impact)

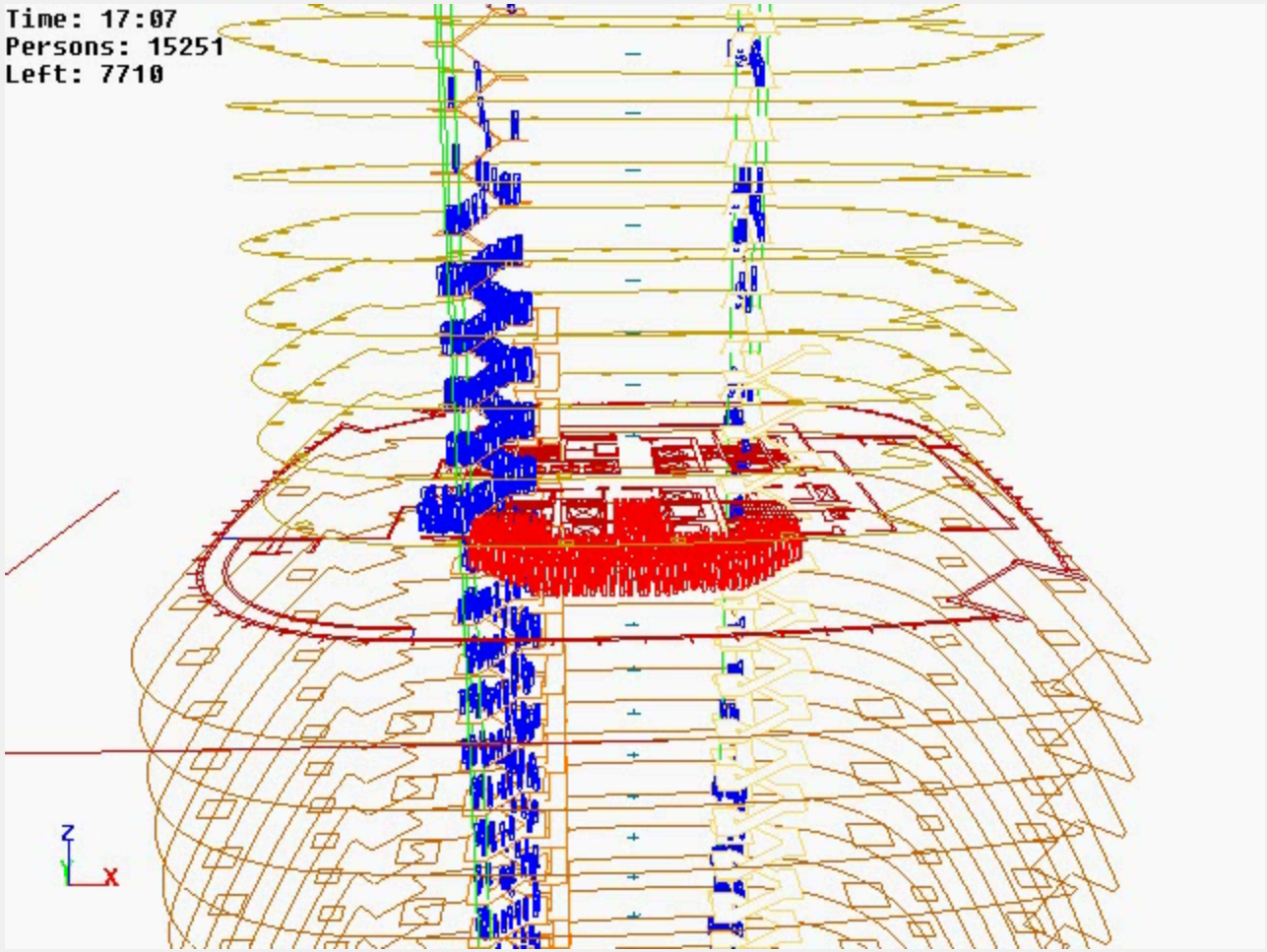
Scenario 1

- Fire between refuge floors
- Consider that,
  - 2 hour or better floors
  - Sprinklers

Evacuate 3 floors

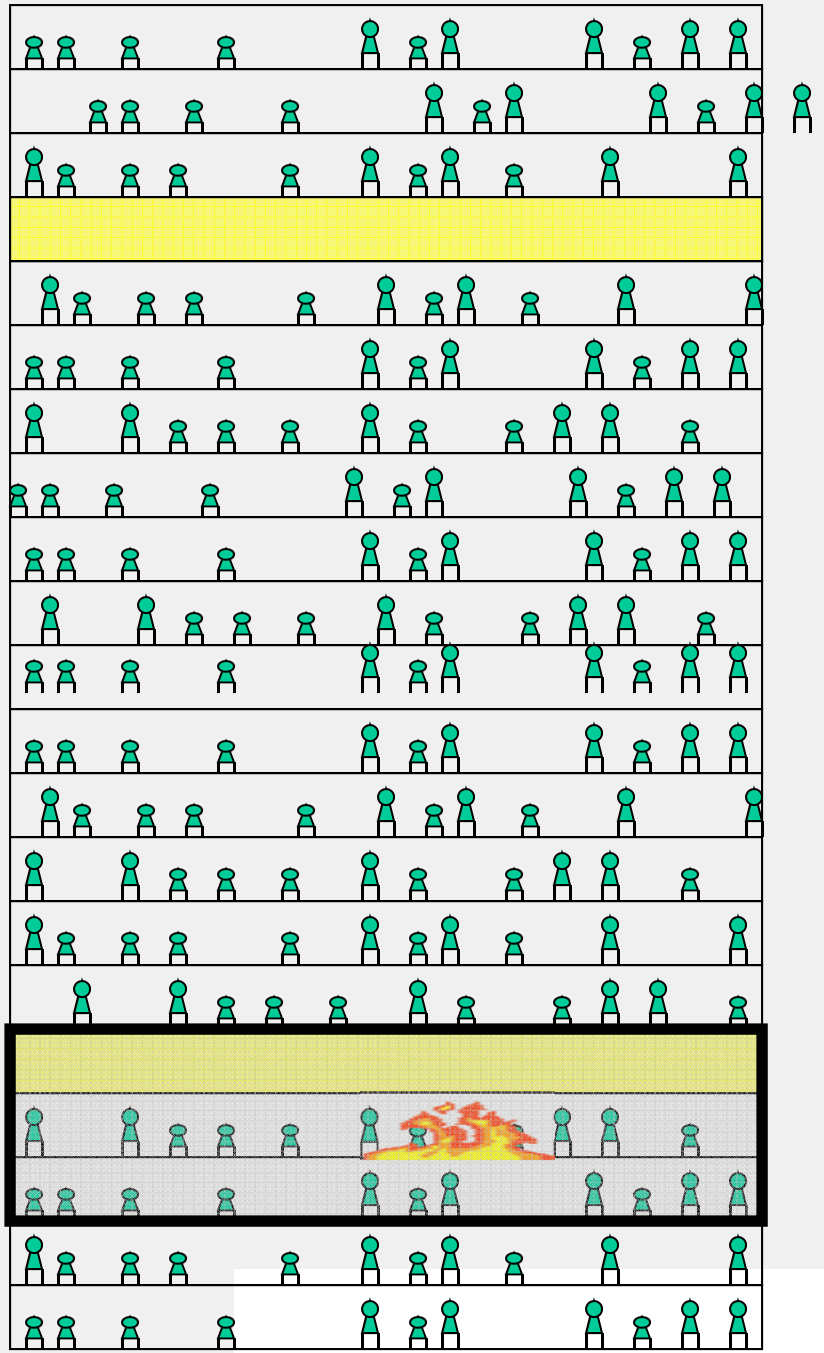


Potential Issues at Refuge floor



Scenario 2

- Fire below refuge floor
- Consider that,
  - 2 hour or better floors
  - Sprinklers



Evacuate 2 floors

Wide Variation Among Codes

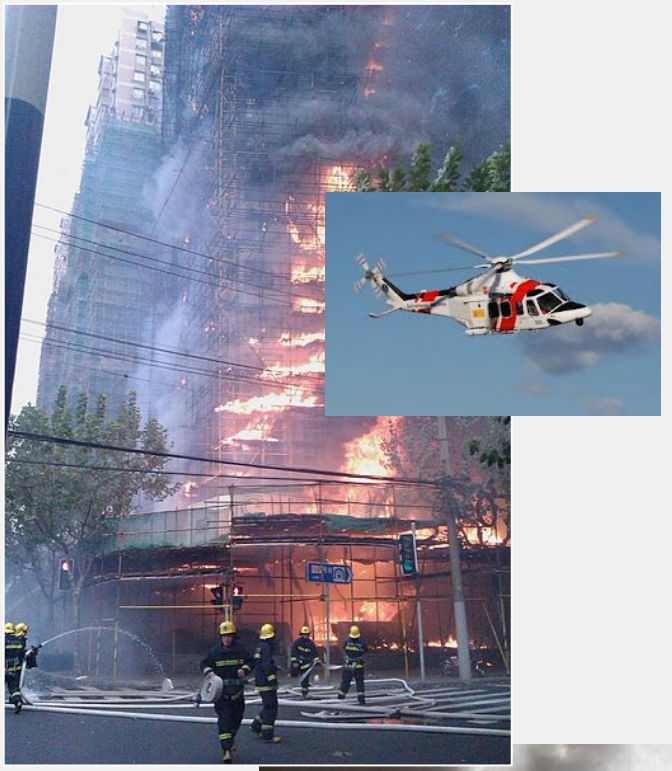
- **When refuge floors are required**
  - > 50 floors or 200 m height (Korea)
  - > 25 stories in height (Hong Kong)
  - > 30 stories (Saudi Arabia)
  - > 24 m in height (India)

- **Example: Implementation Variations**
  - 50% of total gross floor area, every 20/25 stories (Hong Kong)
  - 100% of floor w/mechanical room allowance, every 30 floors (Korea)
  - 15 m^2 or an area equivalent to 0.3 m2 per person to accommodate the occupants of two consecutive floors (India)
  - Refuge floor above 24m, 39m then every 15 m (India)
  - 100% of floor area, every 20 floors (Saudi Arabia)

- **Roof & Helicopter Evacuation**
  - Some authorities strong desire if not requirement for occupants to use roof as refuge and evacuation zone
  - Others see as high-risk strategy

Shanghai Fire - Helicopters

- 15 November 2010
- 28 story Apartment Building
- Exterior scaffolding & welding
- Also, PU foam of exterior wall
- 58 deaths, 70-120 injured



Three helicopters had been called in to assist in the rescue, but were prevented by thick smoke generated by the fire. (China Daily, China Network Television per Wikipedia)

Roof Top Refuge & Helicopters

Flight Safety

- Impact of weather on flight
- Turbulence fire gases impacting helicopter stability

Risk to Human Life

- Occupants on the roof exposed heat/smoke
- Consequences of helicopter crash in an urban setting

Questions of Effectiveness

- Time required to land, load and disembark lacks effectiveness
- Evacuation capacity limited
- Occupants in moving counter to flow down stairs

Why Sprinkler Systems are Key to Safety

- Three buildings
- Non-sprinklered fire losses
- Heat release and smoke volume unmanageable

Moving Forward – Alternatives, Solutions

- Most, if not all floors can serve as refuge space
- Refuge floors can double as usable occupancy
- Buildings w/bridge or horizontal connections need not rely on refuge floors
- Cost savings better spent on reliable fire safety systems – Focus on Sprinkler system reliability, testing and maintenance
- If refuge floors used - Property tax/zoning regulation relief

Fire Safety Concepts Tree – Elevator Evacuation

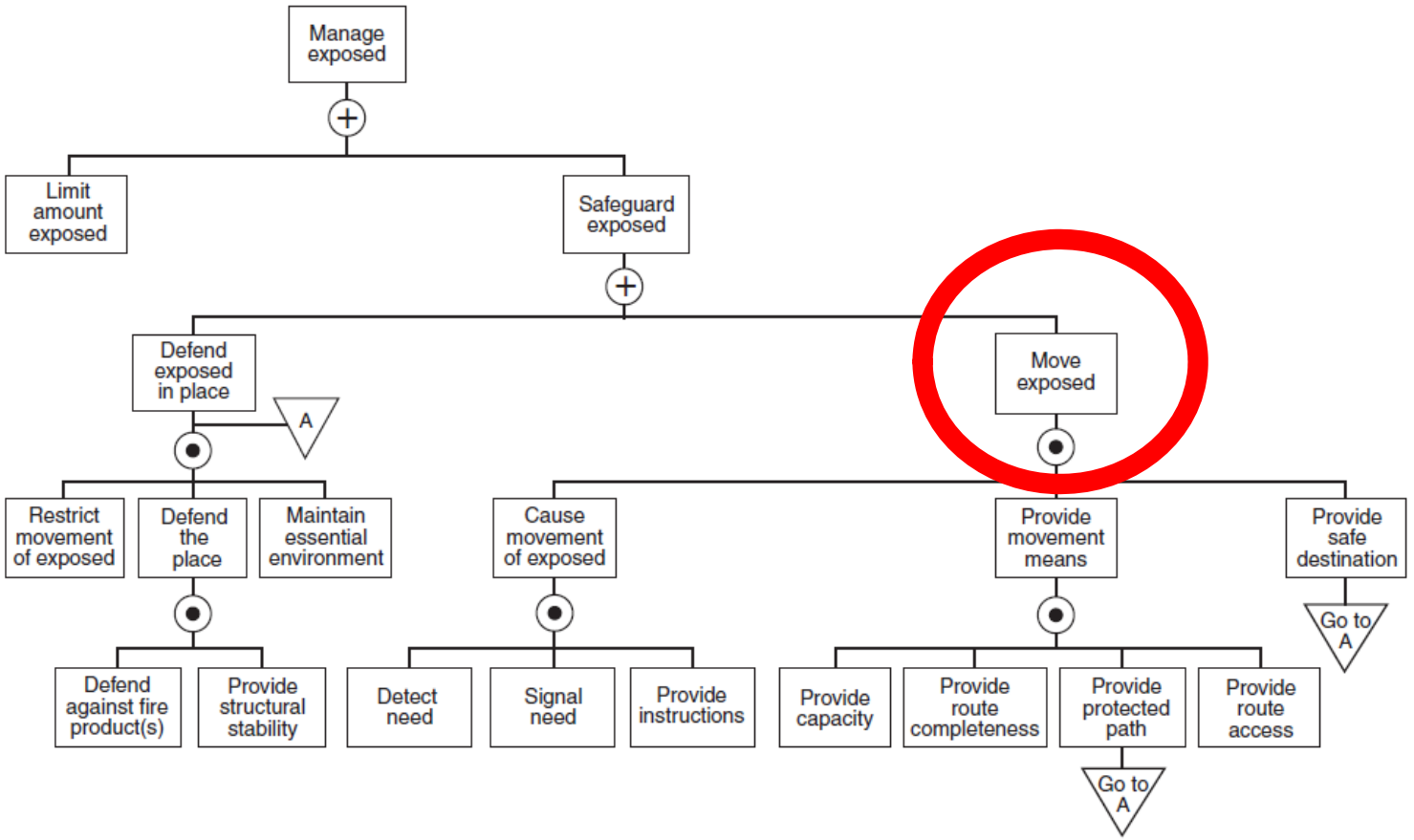


FIGURE 4.5.2.1 "Manage Exposed" Branch of Fire Safety Concepts Tree.

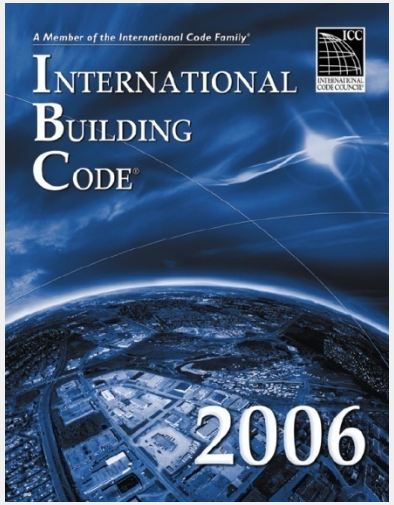
Courtesy NFPA 550

Evacuation Elevators

- First Codified into Building Regulations in IBC 2009
- Provisions for Self Evacuation Elevators as an Alternative to Additional Stairway.
  - Self Evacuation – For Occupant Use with No Attendant
  - Available Prior to Phase 1 Recall
  - Signage to Notify if Elevators are Available for Egress
  - Applies to “All” Elevators in High Rise Building
- Implemented Selectively in U.S.

2006 US PROTECTION OF ELEVATORS

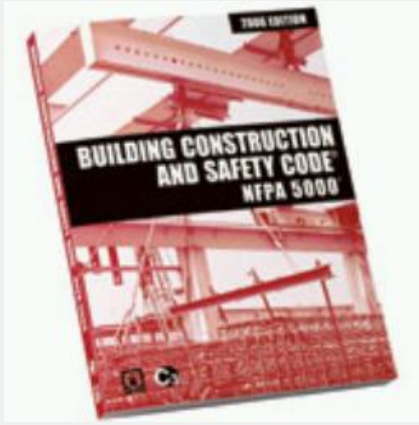
- 2006 IBC SECTION 3002.3
  - "IN FIRE EMERGENCY, DO NOT USE ELEVATOR. USE EXIT STAIRS."
- 2006 IBC SECTION 1007.4
  - ELEVATORS AS ACCESSIBLE MEANS OF EGRESS
    - ASME A17.1 SECTION 2.27
    - STANDBY POWER
    - ACCESSED VIA AREA OF REFUGE OR HORIZONTAL EXIT
- 2006 IBC
  - LIMITED SCOPE FOR EMERGENCY ELEVATORS



International Building Code 2006

2006 US PROTECTION OF ELEVATORS

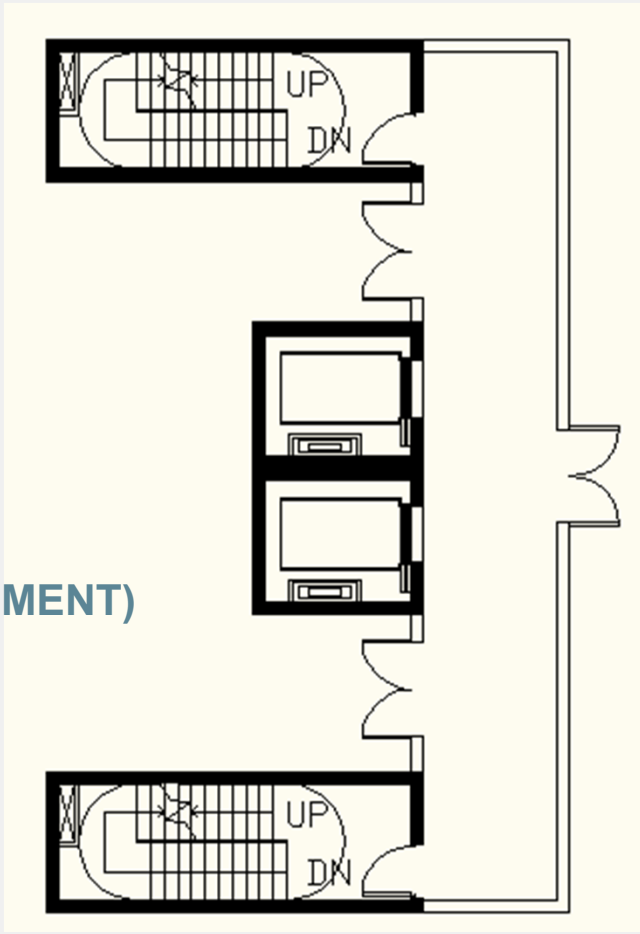
- 2006 NFPA 5000 SECTION 54.1
  - AN ELEVATOR SHALL NOT BE CONSIDERED A COMPONENT IN A REQUIRED MEANS OF EGRESS…
- 2006 NFPA 5000 SECTION 11.2.12.2.4
  - ELEVATORS AS ACCESSIBLE MEANS OF EGRESS
    - ASME A17.1, PROTECTED POWER SUPPLY, SMOKEPROOF ENCLOSURE
- 2006 NFPA 5000 SECTION 11.2.13
  - ELEVATORS IN TOWERS



NFPA 5000 Building Construction and Safety Code 2006

2006 US PROTECTION OF ELEVATORS

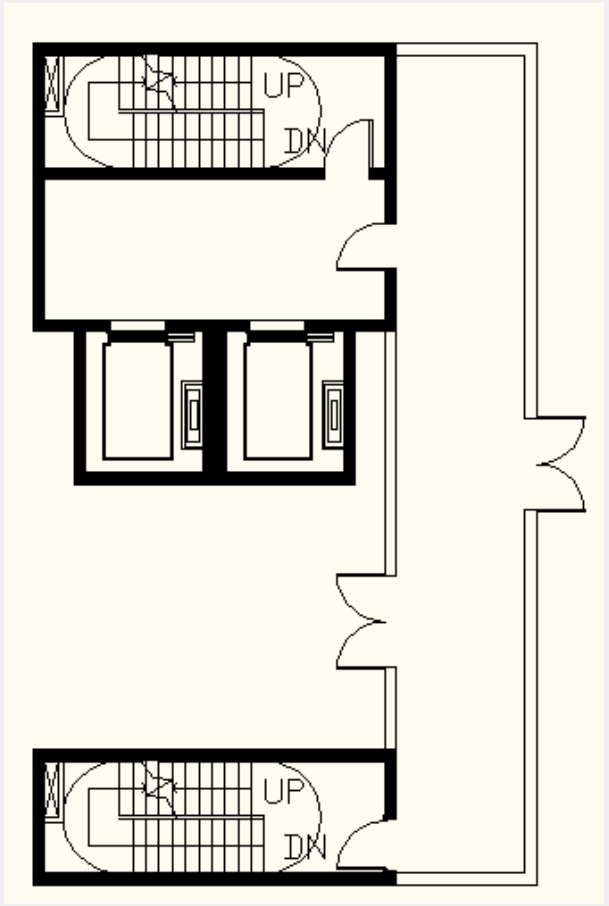
- NFPA 5000 PROTECTED ELEVATOR
  - ASME A17.1
  - PROTECTED POWER SUPPLY
  - FULL FLOOR AREA OF REFUGE
- IBC PROTECTED ELEVATOR
  - ASME A17.1
  - STANDBY POWER SUPPLY
  - NO AREA OF REFUGE (2003 & 2007 SUPPLEMENT)



EUROPEAN UNION STANDARD

- EN 81-72 SAFETY RULES FOR THE CONSTRUCTION AND INSTALLATION OF LIFTS
  - 2 HOUR FIRE FIGHTING SHAFT
    - DIRECT ACCESS TO EXIT STAIR
  - 60 S MAXIMUM TRAVEL TIME
  - WATERPROOF EQUIPMENT (BASED ON LOCATION)

- "FIREFIGHTERS LIFTS ARE NOT ESCAPE ROUTES, SUCH AS STAIRCASES"

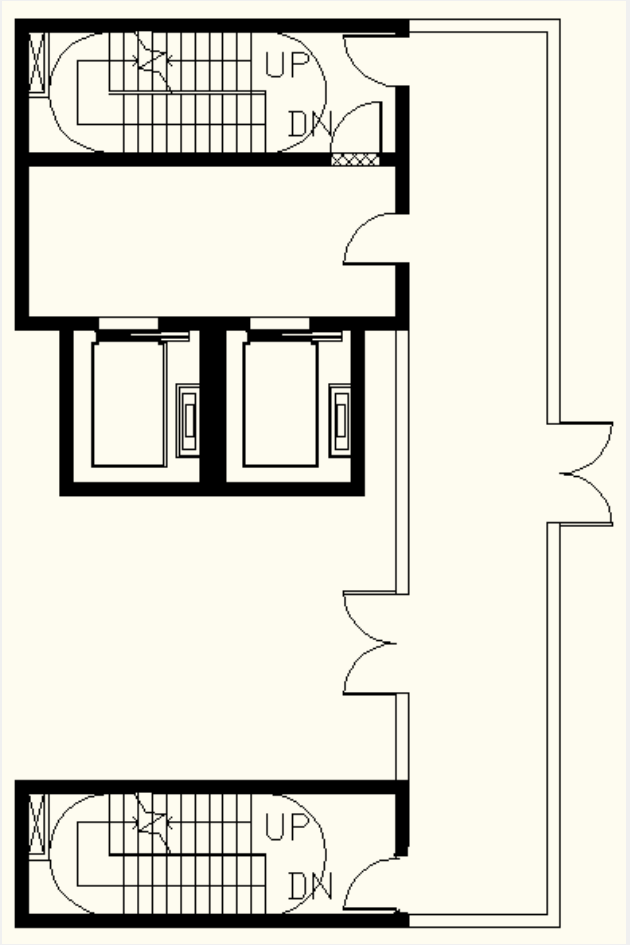


BS EN 81-72:2003

CHINESE STANDARD

- CODE FOR DESIGN OF HIGH-RISE CIVIL BUILDING FIRE PROTECTION
  - FIRE LIFT ANTEROOM (VESTIBULE)
    - MAY BE SHARED WITH STAIR
  - FIRE LIFT WITHIN 30 M OF EXTERIOR
  - 60 S MAXIMUM TRAVEL TIME
  - WATERPROOF EQUIPMENT
  - WATERPROOF ANTEROOM (VESTIBULE)

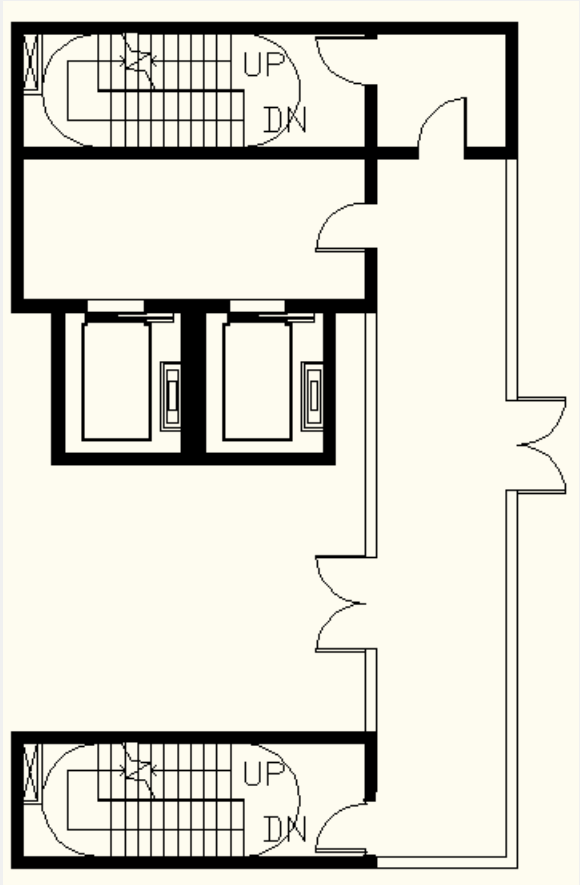
- NO ALLOWANCE FOR EGRESS



Code for Design of High-Rise Civil Building Fire Protection

SOUTH KOREAN STANDARD

- KOREAN BUILDING CODE
  - RATED VESTIBULES
  - PRESSURIZED VESTIBULES
  - FIRE LIFT WITHIN 30 M OF EXTERIOR
  - SECONDARY POWER
  - SEPARATE VESTIBULES
    - EXCEPT RESIDENTIAL
- NO ALLOWANCE FOR EGRESS

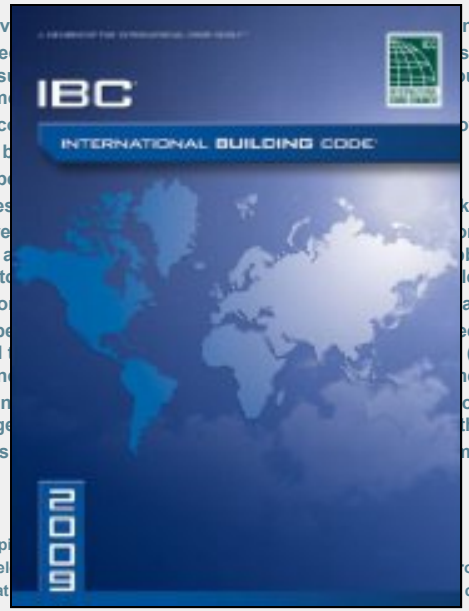


Korean Building Code

2009 US PROTECTION OF ELEVATORS

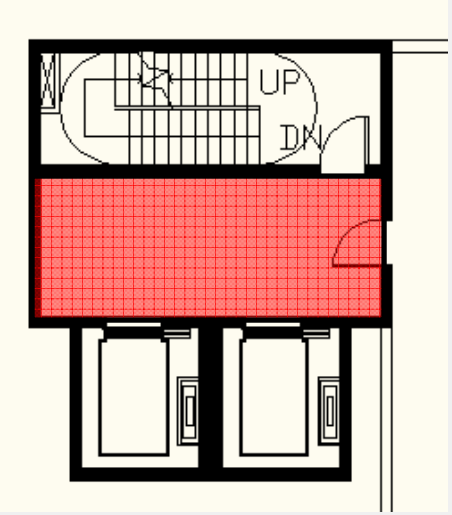
• 2009 INTERNATIONAL BUILDING CODE SECTION 3008

- Fire Safety and Evacuation Plan: The building should have a plan addressing fire safety and occupant evacuation including the use of elevators to evacuate occupants.
- Self Evacuation and Operation: The elevators should be designed in accordance with ASME A17.1/CSA B44 and allow self evacuation prior to Phase I emergency recall.
- Emergency Voice/Alarm Communication System: The building should be equipped with an emergency voice/alarm communication system that is accessible to emergency responders.
- Occupant Notification: Each occupant evacuation elev…ne audible and one visible notification appliance.
- Automatic Sprinkler System: The building should be e…stem except sprinklers should not be located within elevator machine rooms and elevator machine space serving s…uld be monitored with a sprinkler supervisory switch and water floor initiating device provided for each floor that is m…
- High-hazard Content Areas: The building should not c…owable quantities.
- Shunt Trip: Means for elevator shut down should not b…
- Hoistway Enclosure Protection: The elevator should b…
- Water Protection: The elevator hoistway should be des…klers from spreading into the hoistway.
- Elevator Lobby: The elevator should open at each leve…ors, except at the level of discharge. Each lobby door should include a vision panel of fire protection-rated glazing a…bby should have access to a stair. Each occupant evacuation elevator lobby should be sized at 0.28 m² per person t…lchair space (760 mm x 1220 mm) for each 50 persons.
- Signage: A sign should be provided within the elevato…ant self evacuation.
- Status Indicator: The elevator lobby should be equippe…en light stating "Elevators available for occupant evacuation" when the elevators are operating in normal mode and t… (2) an illuminated red light stating "Elevators out of service, use exit stairs" when the elevators are in Phase I emergen…message when the elevators are operating in normal service.
- Two-way Communication System: A two-way commun…obby for initiating communication with the fire command center. The system should include audible and visible signag…the use of the system.
- Elevator System Monitoring: The evacuation elevators…mand center or an approved central control point and should display the following information:
  - Floor location of the elevator cab.
  - Direction of travel of the elevator cab.
  - Status of the cab with regards to whether it is occup…
  - Status of normal power to the elevator equipment, el…oom ventilation and cooling equipment.
  - Status of standby or emergency power systems that…controller cooling equipment, and elevator machine room ventilation and cooling equipment.
  - Activation of any fire alarm initiating device in any elevator lobby, elevator machine room, or elevator hoistway.
- Elevator Recall: The fire command center or approved alternate location should be provided a means to manually initiate Phase I Emergency Recall in accordance with ASME A17.1/CSA B44.
- Electrical Power: The elevator equipment, elevator machine room ventilation and cooling equipment, and elevator controller cooling equipment should be supplied by both normal power and Type 60/Class 2/Level 1 Standby power.
- Protection of Wiring or Cables: Wiring or cables that provide normal and standby power, control signals, communication with the car, lighting, heating, air conditioning, ventilation and fire-detection systems shall be provided by construction having a minimum 1 hour fire-resistance rating or shall be circuit integrity cable having a minimum 1 hour fire-resistance rating.



2009 US PROTECTION OF ELEVATORS

- 2009 INTERNATIONAL BUILDING CODE SECTION 3008
  - SELF EVACUATION
    - PRIOR TO PHASE I
    - FIRE SAFETY AND EVACUATION PLAN
  - 1 HOUR ELEVATOR LOBBY TO HOUSE 25% OCC. LOAD (0.28 m^2 / OCC)
    - PLUS 1 WHEELCHAIR SPACE (760X1220mm) / 50 OCCUPANTS



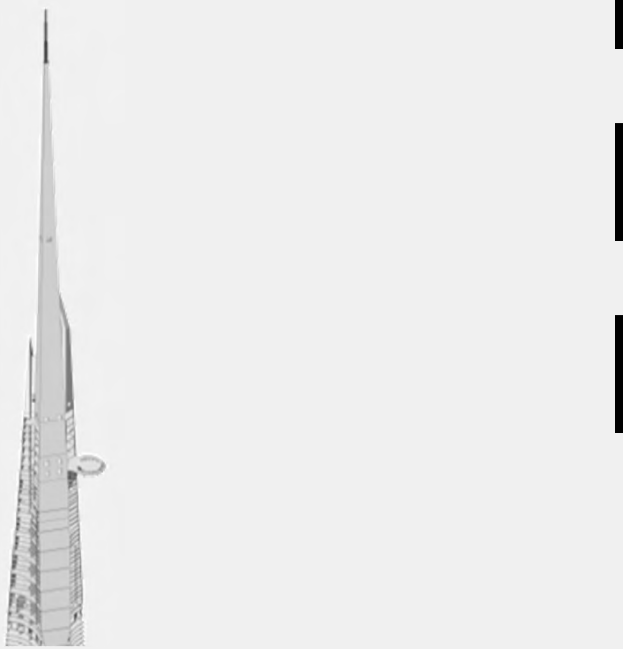
OCCUPANT LOAD:	400
25% OCCUPANT LOAD:	100
ELEVATOR LOBBY SIZE:	28 m^2
PLUS 8 WHEELCHAIR SPACES:	8 m^2
TOTAL ELEVATOR LOBBY SIZE:	36 m^2

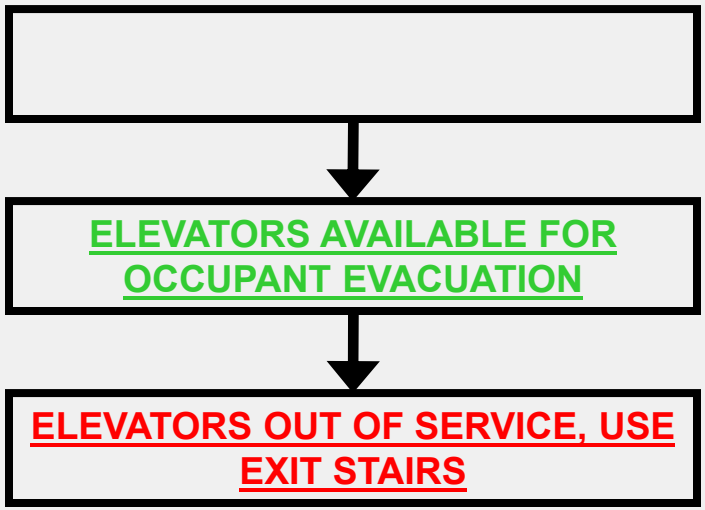
2009 US PROTECTION OF ELEVATORS

- 2009 INTERNATIONAL BUILDING CODE SECTION 3008
  - AUTOMATIC SPRINKLER SYSTEM
    - NO SHUNT TRIP
    - WATER PROTECTION OF LOBBIES
  - THIRD STAIR REQUIRED FOR BUILDINGS OVER 420 FT
    - EVACUATION ELEVATOR MAY SUBSTITUTE THIRD STAIR

2009 US PROTECTION OF ELEVATORS

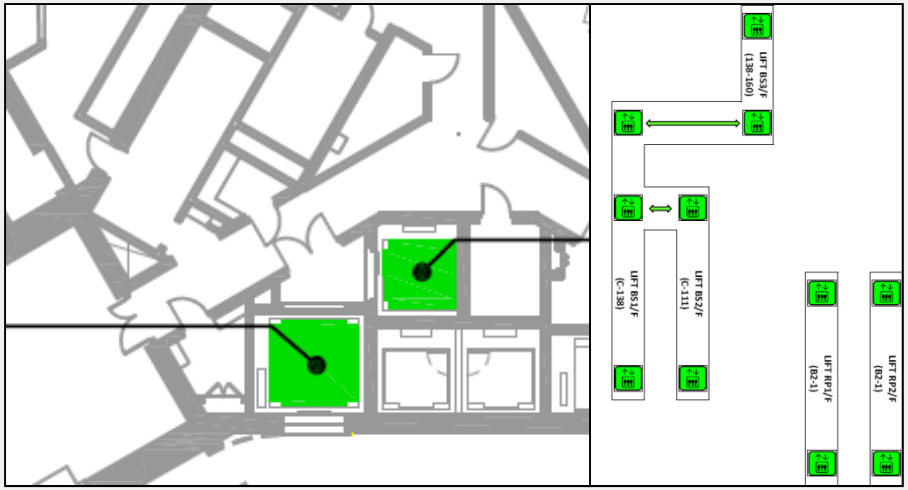
- 2009 INTERNATIONAL BUILDING CODE SECTION 3008
  - SIGNAGE AND STATUS INDICATOR
    - NO LIGHT OR MESSAGE
    - GREEN LIGHT “ELEVATORS AVAILABLE FOR OCCUPANT EVACUATION”
    - RED LIGHT “ELEVATORS OUT OF SERVICE, USE EXIT STAIRS”





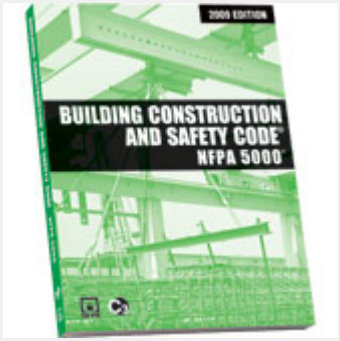
2009 US PROTECTION OF ELEVATORS

- 2009 INTERNATIONAL BUILDING CODE SECTION 3008
  - ELEVATOR SYSTEM MONITORING
    - FLOOR LOCATION OF THE ELEVATOR CAB
    - DIRECTION OF TRAVEL OF THE ELEVATOR CAB
    - STATUS INDICATING THE CAB IS OCCUPIED
    - STATUS OF NORMAL POWER
    - STATUS OF STANDBY OR EMERGENCY POWER SYSTEMS
    - ACTIVATION OF ANY FIRE ALARM INITIATING DEVICE



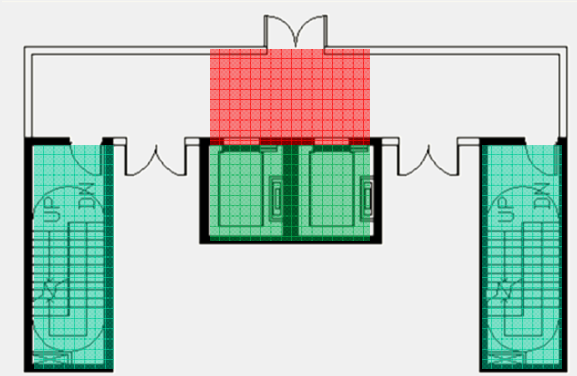
2009 US PROTECTION OF ELEVATORS

- 2009 NFPA 5000 APPENDIX E
  - EVACUATION ELEVATORS SHALL NOT BE SUBSTITUTED FOR REQUIRED MEANS OF EGRESS
  - ADDITIONAL REQUIREMENTS SIMILAR TO IBC

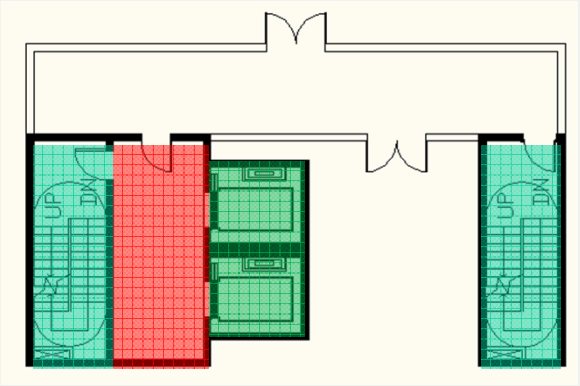


2009 US PROTECTION OF ELEVATORS

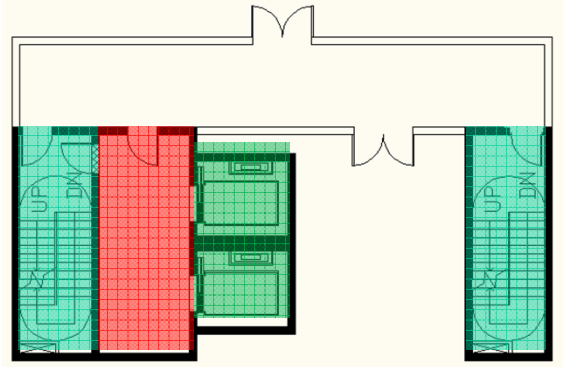
- US STANDARD



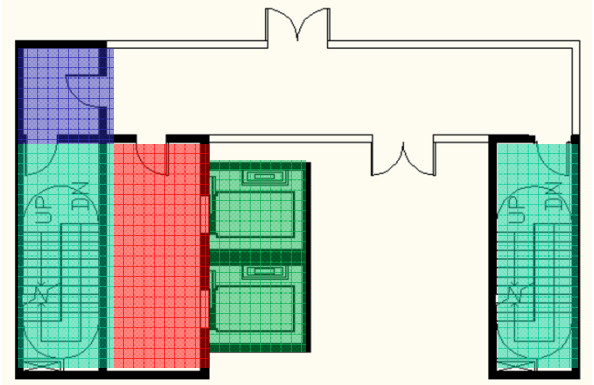
- EUROPEAN STANDARD



- CHINESE STANDARD



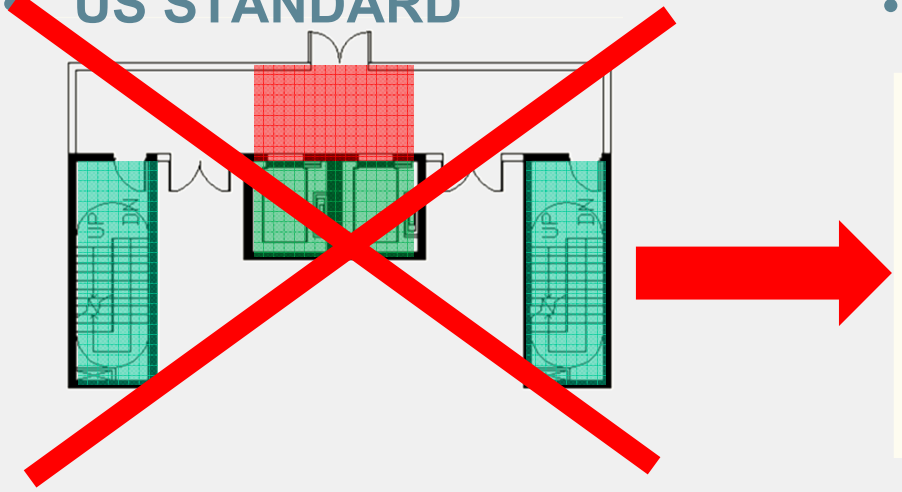
- KOREAN STANDARD



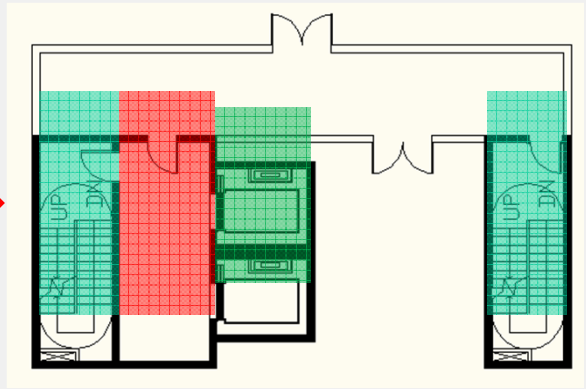
2012 US PROTECTION OF ELEVATORS

– ***Occupant evacuation elevator lobby shall have direct access to an interior exit stairway or ramp***

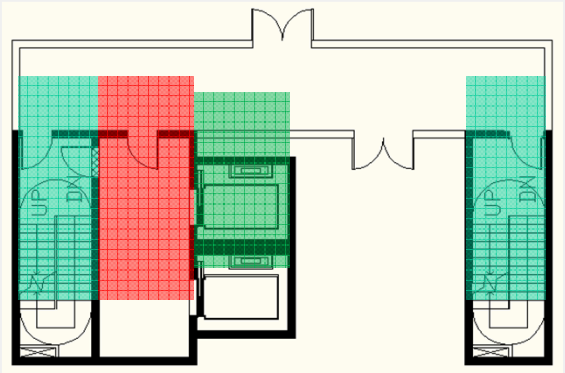
- **US STANDARD**



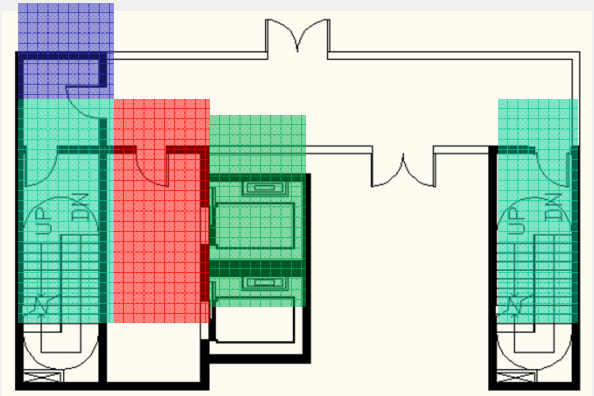
- **EUROPEAN STANDARD**



- **CHINESE STANDARD**

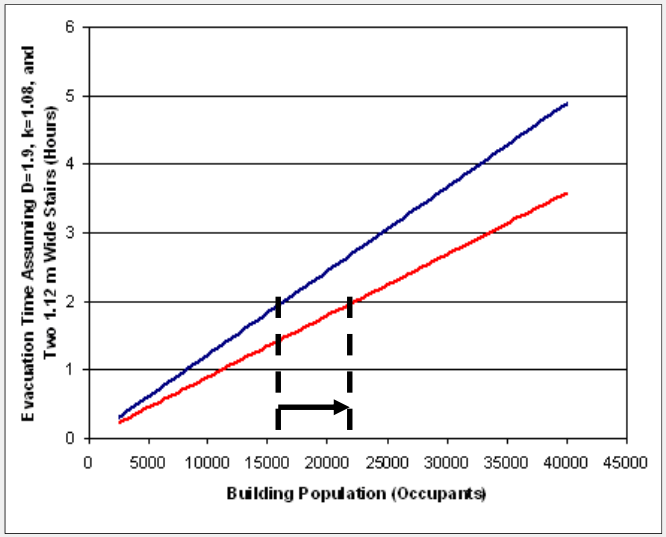


- **KOREAN STANDARD**



DESIGN CONSIDERATIONS

- VALUE OF EVACUATION ELEVATORS
  - TRADE-OFFS (2009 IBC)
  - REDUCTION IN EVACUATION TIME
  - SAFE EVACUATION FOR OCCUPANTS

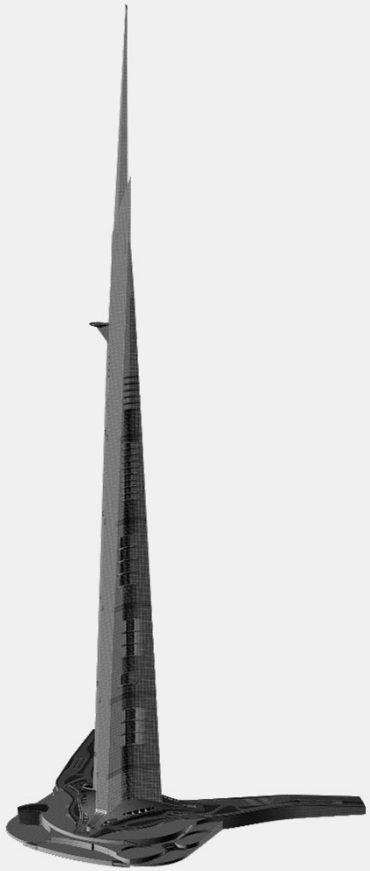


- EVACUATION STRATEGY
  - PRE VS POST PHASE I EVACUATION
    - BUILDING CHARACTERISTICS
    - ACCEPTABLE RISK
  - ACCOMMODATE STRATEGY IN DESIGN
    - BUILDING CORE TO FACILITATE SHARED VESTIBULE
    - FLOOR AREA TO BE PLANNED FOR AREAS OF REFUGE

Contemporary Design: Kingdom Tower

- Located in Jeddah, KSA
- Part of Kingdom City Development
- Mixed-Use
  - Office
  - Hotel
  - Residential
  - Observation Levels
- GFA: 320,000 SM
- Height: 1,000+ Meters

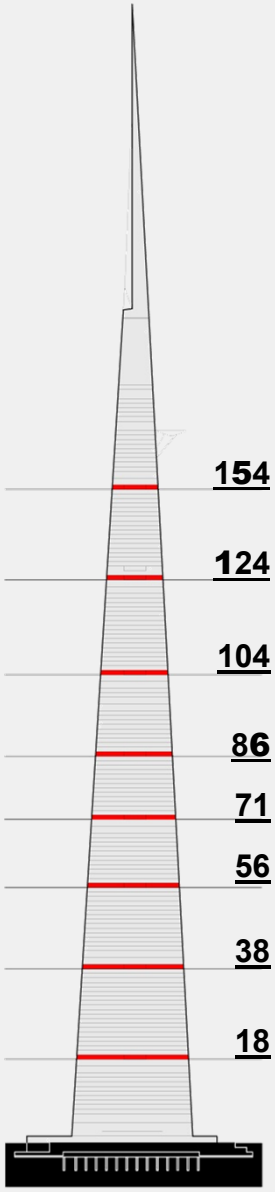
Kingdom Tower – Building Program



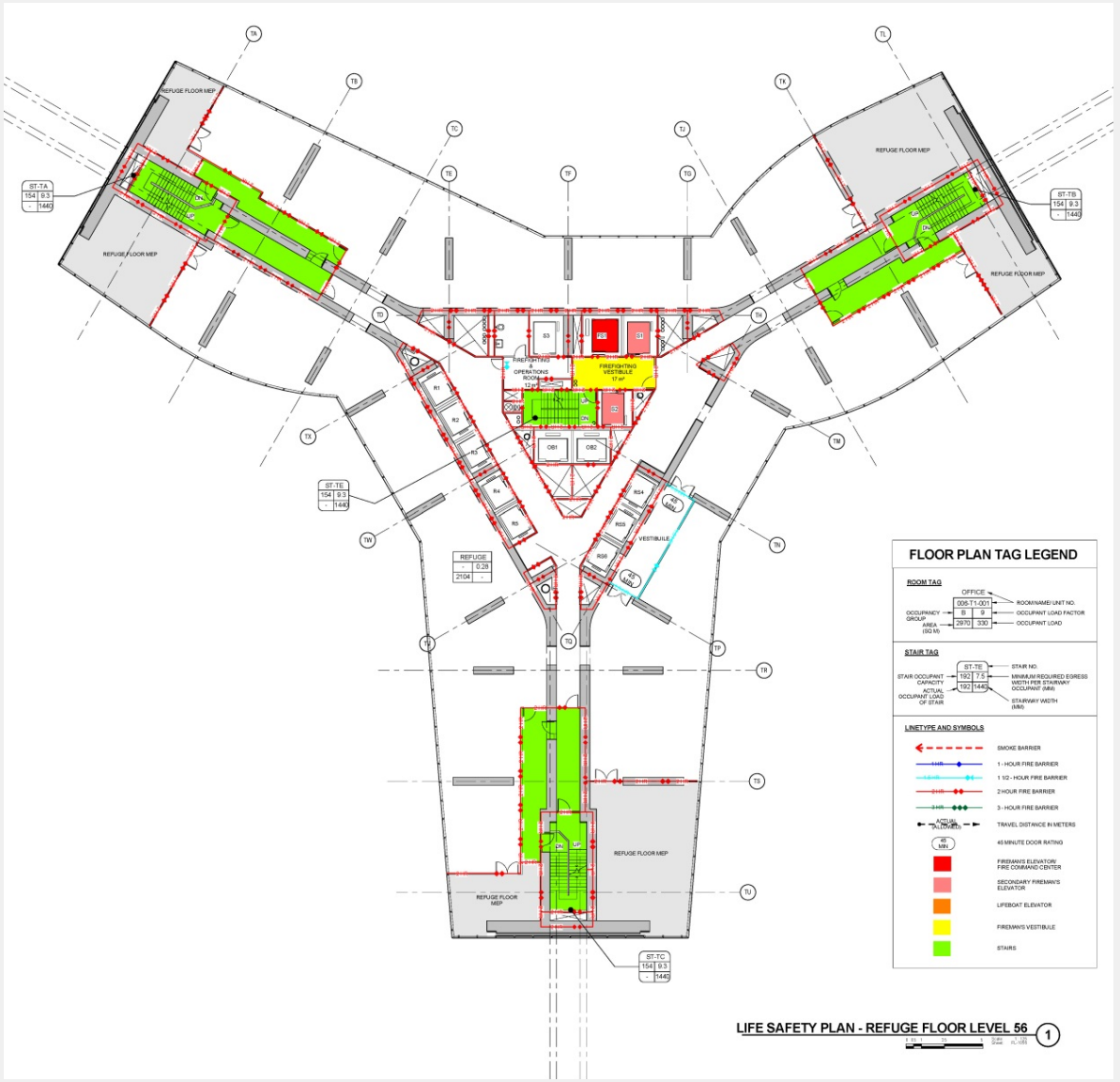
LEVELS	PROGRAM	AREA
LEVEL 157 – 159	Observatory & Sky Terrace	1,583 m2
LEVEL 126 – 153	Void Space – No Occupancy	1,618 – 1,167 m2
LEVEL 99 - 120	Residential – Group 4	1,552 – 1,143 m2
LEVELS 87 – 94	Residential – Group 3	1,572 – 1608 m2
LEVELS 73 – 83	Residential – Group 2	1,841 – 1,698 m2
LEVELS 44 – 67	Residential – Group 1	2,094 – 1,893 m2
LEVELS 27 – 37	Service Apartments	2,057 – 2,120 m2
LEVELS 20 – 26	Hotel Guest Rooms	2,148 – 2,269 m2
LEVELS 7 – 14	Office	2,756 – 2,682 m2
LEVELS B2 - 6	Lobbies, Hotel Function Spaces, Spa	14,992 – 2,757 m2
LEVELS B3 – B1	Parking	47,718 - 20,511 m^2

Refuge Floors

- Located Every 20 Floors
- Full Floor Refuge Areas
- Stairs are Discontinuous at Refuge Floors
- Refuge Floors are Mechanically Pressurized
- A Fire Officer is Resident in Each Refuge Floor
- Queuing Point for Evacuation Elevators



Refuge Floors

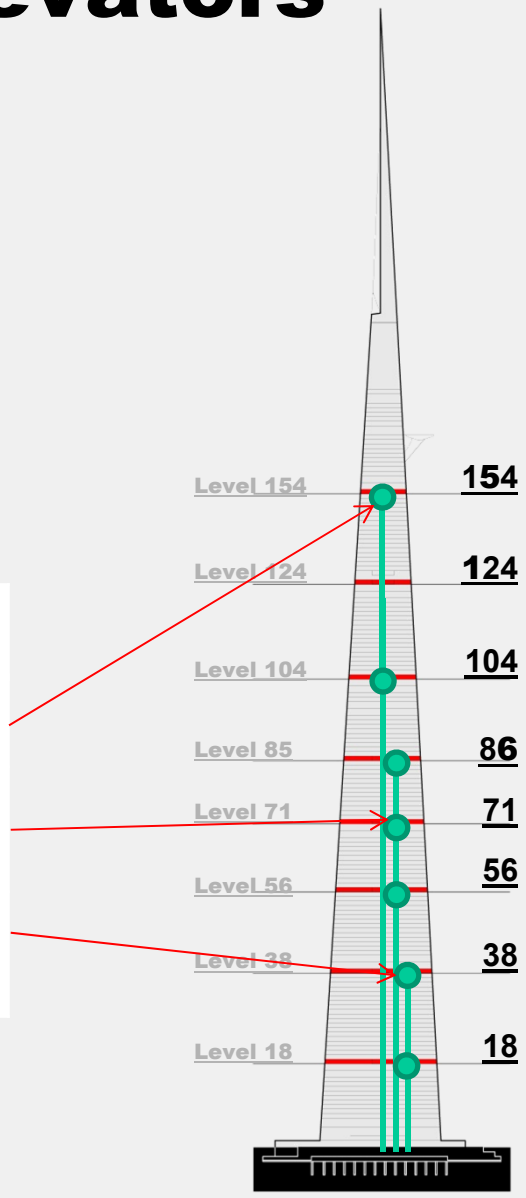


Evacuation Elevators

Kingdom Tower “Lifeboat” Elevators

- High Speed Shuttle Elevators For Evacuation
- Emergency Power & Protection Features
- Lifeboat Elevators Serve Refuge Floors
- Reduce Total Building Evacuation to < 2 Hours

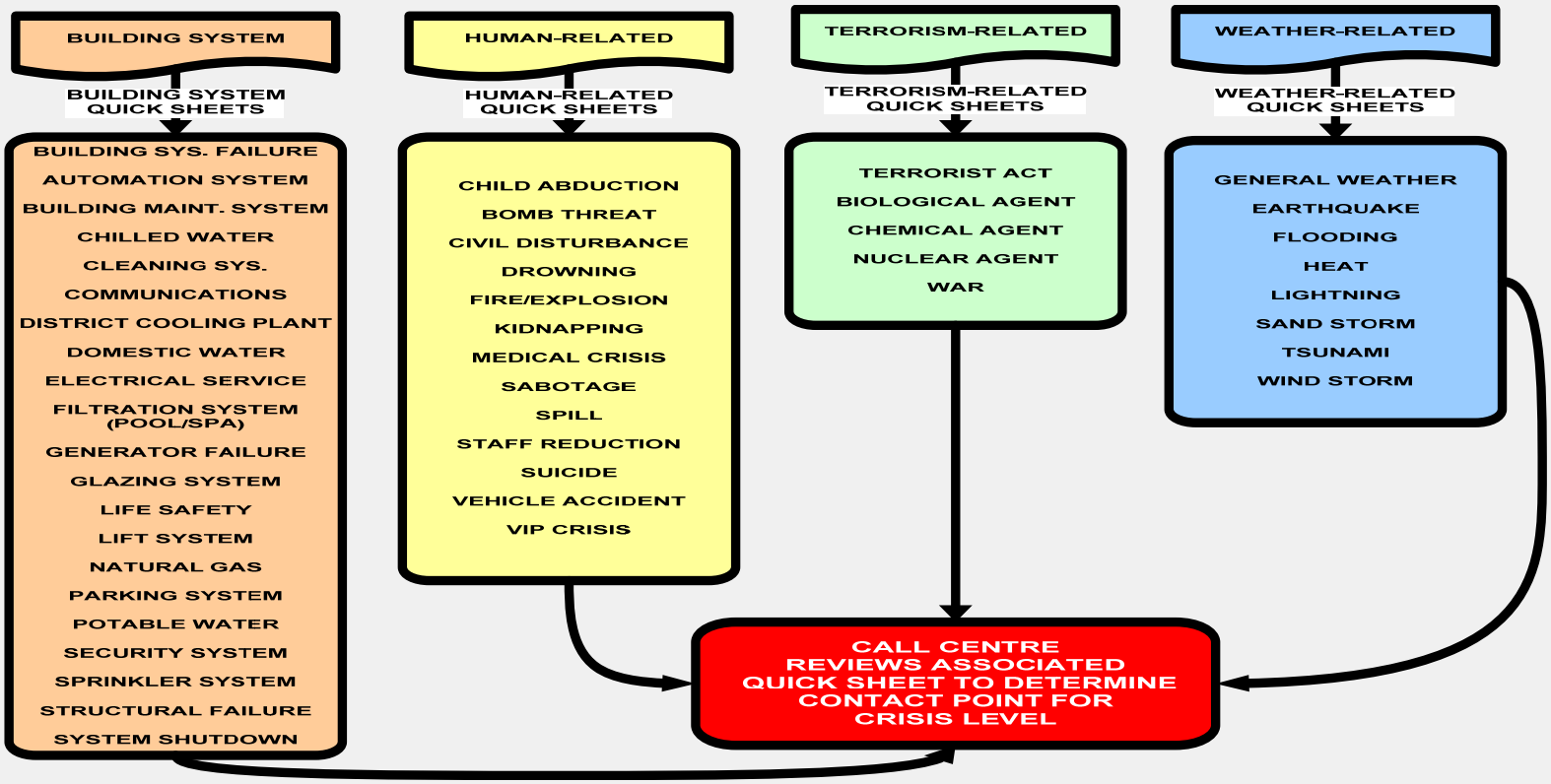
Observation Shuttles OB1, OB2	**Floors 154, 104**
Residential Shuttles R4, R5, R6	**Floors 86, 71, 56**
Residential Shuttles R1, R2, R3	**Floor 38, 18**



Operational Aspects

- Building Operation and Maintenance
  - Adequate Staffing and Training
  - Maintenance of Life Safety Systems
- Crisis Management Plan
  - Define Threats
  - Pre-Planned Response Procedures
  - Training
- Security Issues

Crisis Management Plan



SPECIFIC PROCEDURES DEVELOPED FOR THE VARIOUS CRISES

Courtesy Jensen Hughes

Conclusions

- Special consideration must be given to evacuation from high-rise buildings
- More Active & Passive Protection required
- Design, Construction, and Operational aspects must be considered

Thank you

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