# *Introduction to Fire Safety Engineering*

Dr Eric W.M. Lee
Department of Building and Construction
City University of Hong Kong

1

## Why Fire Safety Engineering?

Existing prescriptive requirements is sufficient for ordinary and traditional building designs which are developed according to prescriptive codes

## Why Fire Safety Engineering?

Performance-based fire engineering is an approach allowed in Code of Practice permits alternative building design deviated from prescriptive requirements but the fire safety is required to be justified by scientific approach.

3

## Major Prescriptive Control in Hong Kong

- Buildings Ordinance
  - Building Construction and Spatial Design
- Fire Services Ordinance
  - Fire Services Installation

4

## Prescriptive Requirement under Building Ordinance

- Building (Planning) Regulation 41(1)
  - Means of Escape
- Building (Construction) Regulation 90
  - Fire Resisting Construction
- Building (Planning) Regulation 41A, 41B and 41C
  - Access Staircase for Firemen, Fireman's Lift, Fire Fighting and Rescue Staircase

5

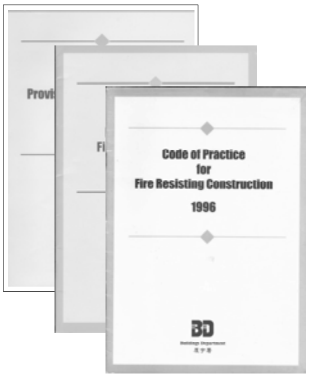
## Prescriptive Guidelines

| | |
|---|---|
| B(R)R 41(1) | Code of Practice for the Provision of Means of Escape In Case of Fire, 1996 |
| B(C)R 90 | Code of Practice for Fire Resisting Construction, 1996 |
| B(C)R 41A to 41C | Code of Practice for Provision of Means of Access for Firefighting and Rescue Purpose, 2006 |
| FSO | Code of Practice for Minimum Fire Service Installations and Equipment |

6

## Codes of Practices

- Means of Escape
- Means of Access
- Fire Resisting Construction




## Prescriptive Guidelines

- MoE Code – Egress Facilities
- FRC Code – Fire Resistance (prevent fire/smoke spread, structural stability)
- MoA Code – Access for fire fighting and rescue
- FSI Code – Control fire size, prevent fire/smoke spread, facilitate escape, etc.

8

## Alternative Approach

- Prescriptive code – too rigid, demand for an alternative approach especially for complex buildings
- Alternative approach – Explicitly allowed by PNAP204

9

## Alternative Approach

PNAP204: Fire engineering design offers a flexible alternative where it is impracticable to comply with prescriptive provisions in the codes, especially when designing for special or large and complex buildings or alteration and addition works in existing buildings.

10

## Fire Engineering Design

ISO technical committee in Fire Engineering (ISO/TC92/SC4)

- *The application of engineering principles, rules and expert judgment based on a scientific appreciation of fire phenomena, of the effects of fire, and of the reaction and behaviour of people, in order to:*
  - *save life, protect property and preserve the environment and heritage*
  - *quantify the hazards and risk of fire and its effects*
  - *evaluate analytically the optimum protective and preventive measures necessary to limit, within prescribed levels, the consequences of fire*

11

## Purpose

- Fire safety engineering design provides a framework to demonstrate that the performance requirements of legislation are met (or better), even though the design solutions adopted fall outside the prescriptive recommendations

12

## Building Design

- Straightforward – Adhere to prescriptive rules
- Innovation or difficult to A&A – Fire safety engineering approach

13

## Fire Safety Engineering Design

- Studies involve the interactions between fire, people and building(s)
- It is an extremely complicated phenomenon
- Impossible to use single set of evaluation procedures for all buildings

14

## General Framework

- review the architectural design
- identify non-compliance items and potential fire hazards
- define the problem in qualitative terms suitable for detailed quantitative analysis (fire safety objectives)
- establish one or more fire protection schemes to meet the fire safety criteria (generating ideas for alternatives
- formulate the basis for evaluation
- carry out quantitative analysis

15

## Approaches

- Probabilistic Approach – evaluate the fire risk level by probabilistic evaluation
- Comparative Approach – demonstrate the performance of the alternative design is at least equivalent to the code compliance design
- Deterministic Approach – evaluate the fire safety level by computer simulation on fire/smoke spread and evacuation pattern

16

## Approaches Commonly Adopted

- Minor non-compliance
  - Demonstrate like-to-like substitution and/or equivalent [Comparative Approach]
- Major different with prescriptive requirements
  - Carry out total fire safety evaluation to demonstrate that the fire safety level of the alternative design is acceptable [Deterministic Approach]

17

## What is equivalence?

Equal performance between the designed system and what is expected under full compliance with the prescriptive requirements

18

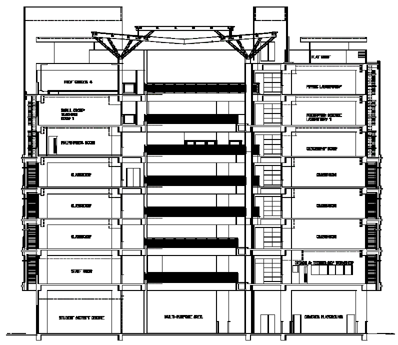
## Like-to-Like Approach

Example

A steel roof is to be provided to cover an open atrium of a school. Balcony Approach is no longer valid. Use Like-to-Like approach to demonstrate the equivalency of performance with and without the steel roof.

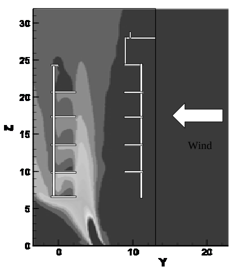


## Like-to-Like

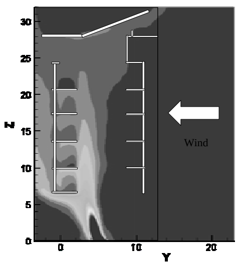




## Like-to-Like Approach




Without roof cover




With roof cover



## Like-to-Like Approach

Example

Protected lobbies which is stipulated by fire codes to protect openings in compartment walls can be substituted by using fire shutters. However, in some situations such as between carparks, any such opening cannot be protected by fire shutters [paragraph 10.1 of FRC Code, 96 refers].

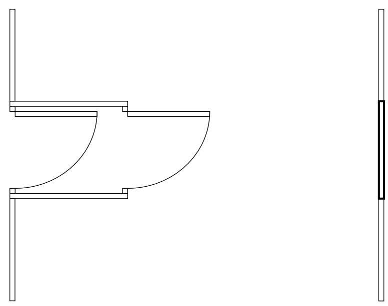


## FRC para 10.1

Opening may be made in compartment walls for communication, but not combination, of adjoining compartments, provided that the openings are protected by a lobby with doors. **Except** for places of public entertainment or **carparks**, any such opening may alternatively be protected by a fire shutter with the same FRP as the wall with regard to the criterion of integrity.



## Example



Protected Lobby

Fire Shutter

## COP – FRC Table 3

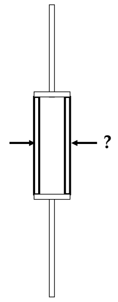
| Elements of construction or other components | Criteria to be satisfied | | | Method of exposure |
|---|---|---|---|---|
| | Stability | Integrity | Insulation | |
| 7. Protected shaft, lobby and corridor | Y* | Y | Y | each side separately |
| 8. Fire shutter, fire stop or barrier | N | Y | N | each side separately |

Notes : (1) Y = required
N = not applicable
Y* = required for loadbearing elements only



## Suggestion

- Alternative Design
  - Double Fire Shutter
- To demonstrate that a special double fire shutter system is equivalent to a protected lobby




Double Fire Shutter



## Insulation failure when …

*(BS476, Part 20)*

1. If the mean unexposed face temperature increases by more than 140°C above its initial value
2. If the temperature recorded at any position on the unexposed face is in excess of 180°C above the initial mean unexposed face temperature
3. When integrity failures



## Demonstration can be done by …

- Experiment (…Destructive and Expensive)
- Computation



## Computation Tool

Using computational fluid dynamics (CFD) technique to evaluate the temperature rise at the unexposed side of the arrangement due to conduction, convection and radiation through the air-cavity formed between the two fire shutters.



## Standard Fire Test

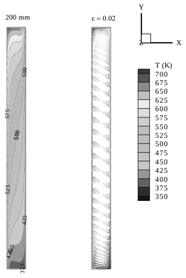
Standard Temperature-Time Curve [BS476:Part20]

$$T = 345\log_e(8t+1) + T_o$$

Where $T$ = fire temperature $^oC$
$T_o$ = initial temperature in $^oC$
$t$ = time in minutes

# With 200mm air cavity

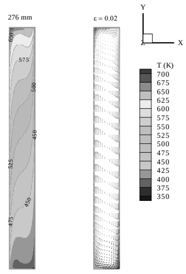
**Steady-state temperature contours and velocity field air-cavity width of 200 mm and emissivity of 0.02**






# With 276mm air cavity

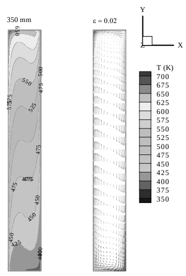
**Steady-state temperature contours and velocity field air-cavity width of 276 mm and emissivity of 0.02**






# With 350mm air cavity

**Steady-state temperature contours and velocity field air-cavity width of 350 mm and emissivity of 0.02**






# CFD Simulation Results

(emissivity=0.02)

| Widths of air cavity (mm) | Unexposed face temperature (°C) | |
|---|---|---|
| | Average (Rise) | Maximum (Rise) |
| 200 | 135.42 (110.42) | 220.35 (195.35) |
| 276 | 135.90 (110.90) | 216.32 (191.32) |
| 350 | 136.36 (111.36) | 206.53 (181.53) |
| **400** | 136.81 (111.81) | 201.25 (176.25) |
| 500 | 137.67 (112.67) | 194.88 (169.88) |



# Deterministic Approach

Deterministic study: Methodology, based on physical relationships derived from scientific theories and empirical results that, for a given set of initial conditions, will always produce the same outcome. (Clause 3.6 of PD7974: Part 0: 2002)



# General Approach

Establish the worst credible fire scenarios

⇩

Describe the scenarios by fundamental physical, chemical & thermodynamic principles or empirical results

⇩

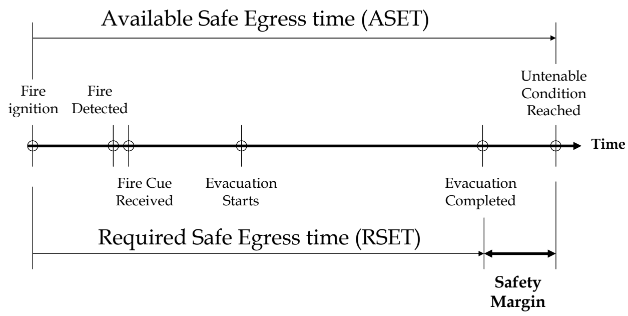
Evaluate the fire safety level

## Safety Factor

*Where there is doubt as to the reliability of input data or calculation procedures a conservative approach should be adopted !*

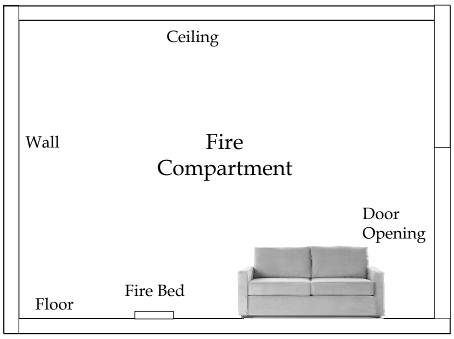


## Timeline Approach



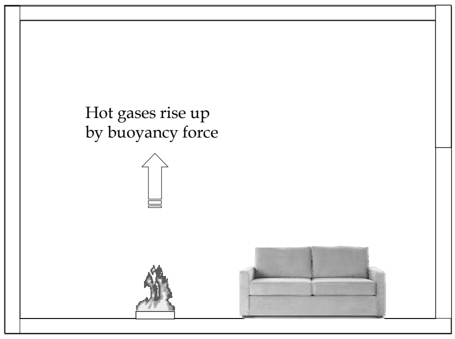



## Enclosure Fire Dynamics



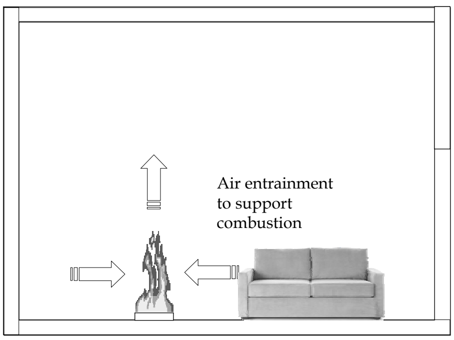



## Enclosure Fire Dynamics



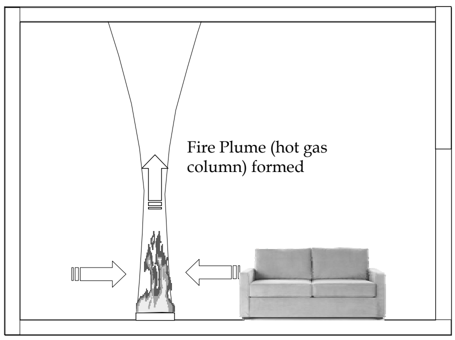



## Enclosure Fire Dynamics

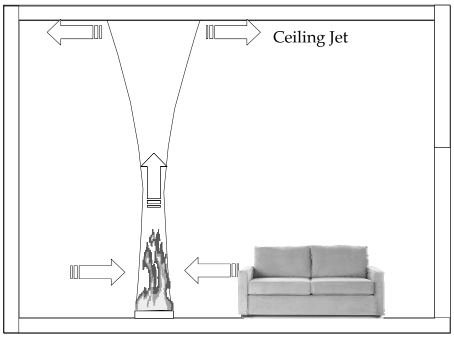





## Enclosure Fire Dynamics

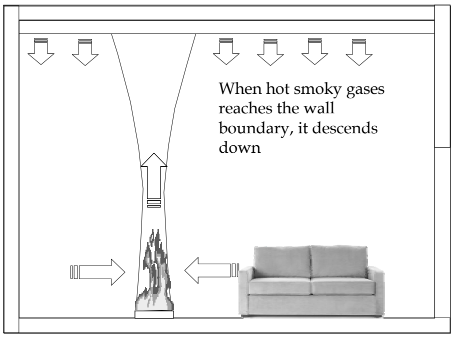


## Enclosure Fire Dynamics



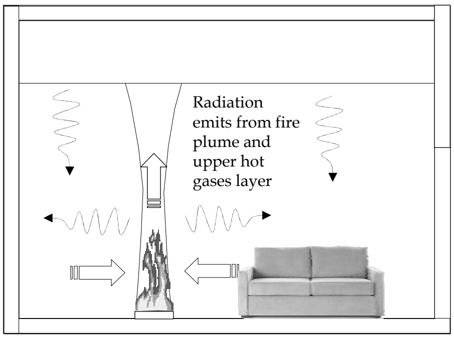

43

## Enclosure Fire Dynamics



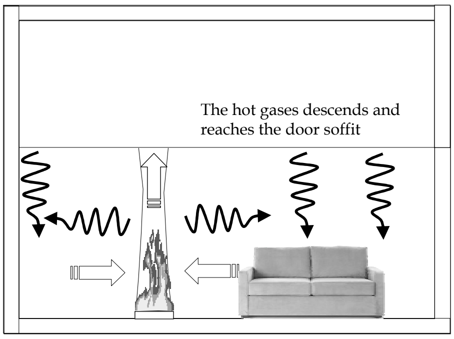

44

## Enclosure Fire Dynamics



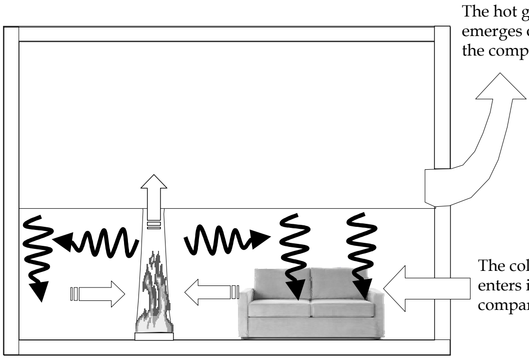

45

## Enclosure Fire Dynamics



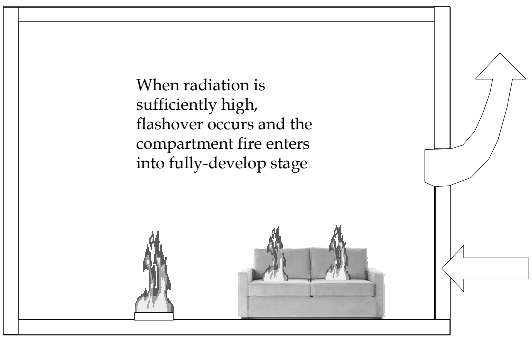

46

## Enclosure Fire Dynamics



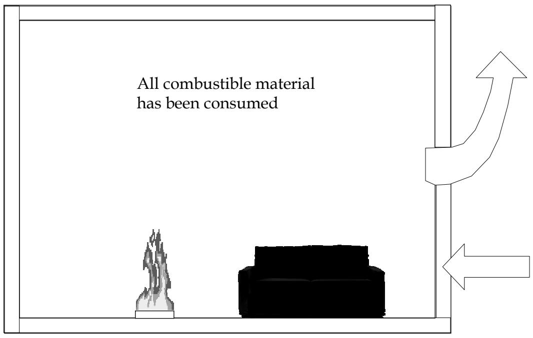

47

## Enclosure Fire Dynamics



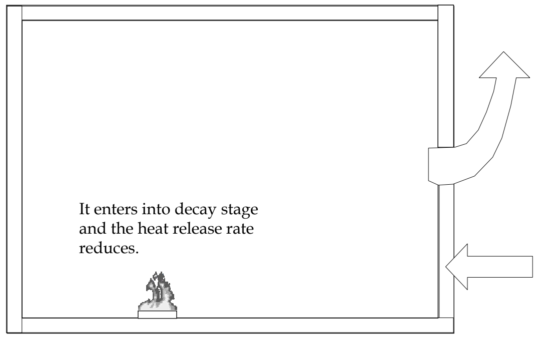

48

## Enclosure Fire Dynamics






## Enclosure Fire Dynamics

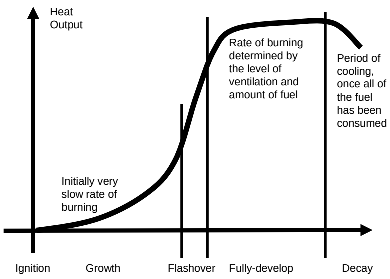





## Compartment Fire Development

Stages

- Ignition
- Growth
- Flashover
- Fully-develop
- Decay



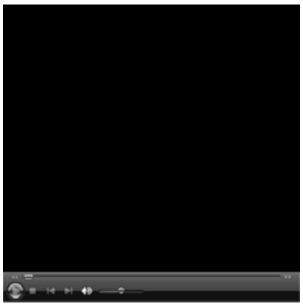



## Flashover – (閃燃)

- Radiant heat from fire plume and hot gases at upper layer is sufficiently high to ignite any combustible material inside the fire compartment at simultaneously
- Some Criteria
  - Hot gas temperature at 10mm below ceiling soffit reaches 500 ~ 600°C above ambient
  - Radiation on floor reaches approx. $20kW/m^2$



## Compartment Fire Development

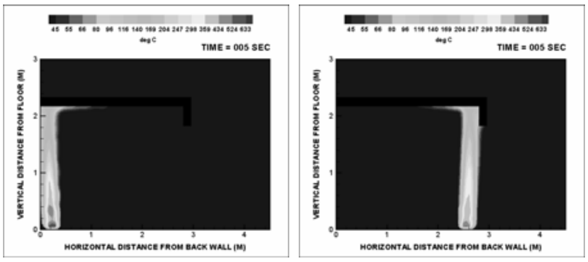




## Overall ASET Evaluation

- By zone modeling (e.g. CFAST, etc.)
- By field modeling (e.g. Computational Fluid Dynamics (CFD))
- By empirical equations (e.g. Equations in SFPE handbook)

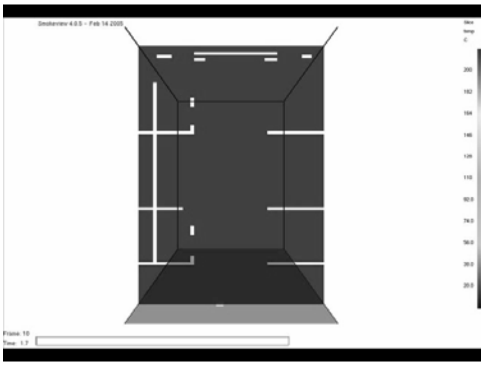
## Field Modeling
## Example – Compartment Fire




Simulated by Fire3D developed by Dr. Richard K.K. Yuen et al. of Department of Building and Construction, City University of Hong Kong



## Field Modeling
## Example - Atrium





## Tenability Limits

- Hot gas temperature
  - 115°C less than 5 minutes
- Radiant intensity
  - 2.5kW/m$^2$
- Smoke height
  - 2.0m (eye level) above finished floor level (usually approximated by height of thermal interface)



## Overall RSET Evaluation

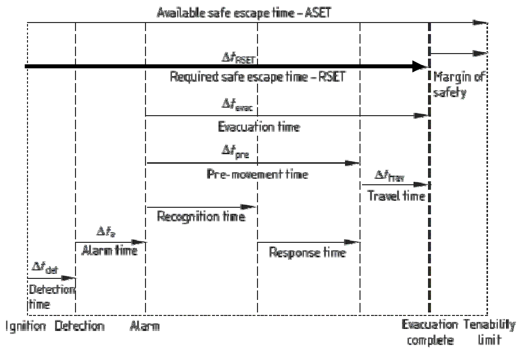



Figure adopted from PD7974:Part 6 (2004)

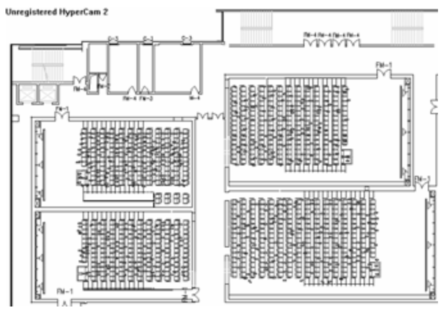


## Evacuation
## Pre-movement Time

- $\Delta t_{det} + \Delta t_a$
  - Smoke intensity, heat, alarm actuation, etc. by numerical simulation (e.g. CFD)
- $\Delta t_{pre}$
  - By design guide and handbook with suitable adjustment for local application
- $\Delta t_{trav}$
  - By numerical simulation using cellular automation, social force model, etc.

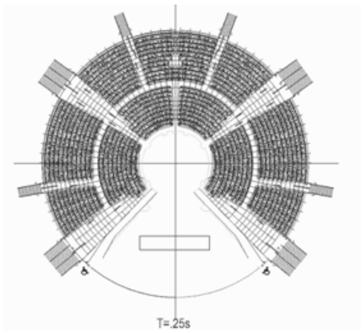


## Evaluation of Traveling Time
## Example - Auditorium



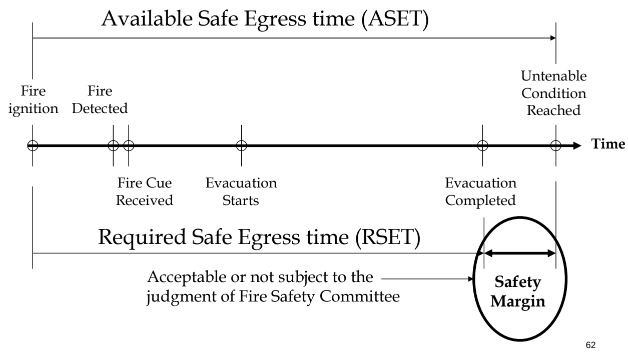

Simulated by SGEM developed by Dr. S.M. Lo et al. of Department of Building and Construction, City University of Hong Kong

## Evaluation of Traveling Time Example - Circus




61

## Safety Margin




62

## Fire Safety Committee (FSC)

- BD surveyor to decide the submission to FSC
- FSC Members – BD's AD, BD's Surveyors, BD's Structural Engineers, Academics from PolyU and CityU, HKIE, FSD's officers
- Meeting on every Wednesday
- Consultant presents the study to FSC
- FSC member raise questions
- Decision will pass back to Surveyor

63

## My comments on fire safety engineering study

- No free lunch! Trade-off is necessary
- It may not save money
- Statutory submission takes time
- Better to carry out the study in design stage
- Future management and maintenance is critical to achieve the fire safety level
- Always do it with the greatest conscience

64

## Summary

- General approaches of fire safety engineering study was discussed
- Example in like-to-like approach was demonstrated
- Timeline approach to evaluate the fire safety level (safety margin) was introduced

65

*Thank You*

66