Fire Safety Engineering Workshop
Session II: Technical Methods for Fire Safety

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Quality Fire Safety Management

Presented at the Fire Safety Engineering Workshop at Sichuan Fire Research Institute, May 26-27, 2015, Chengdu, China

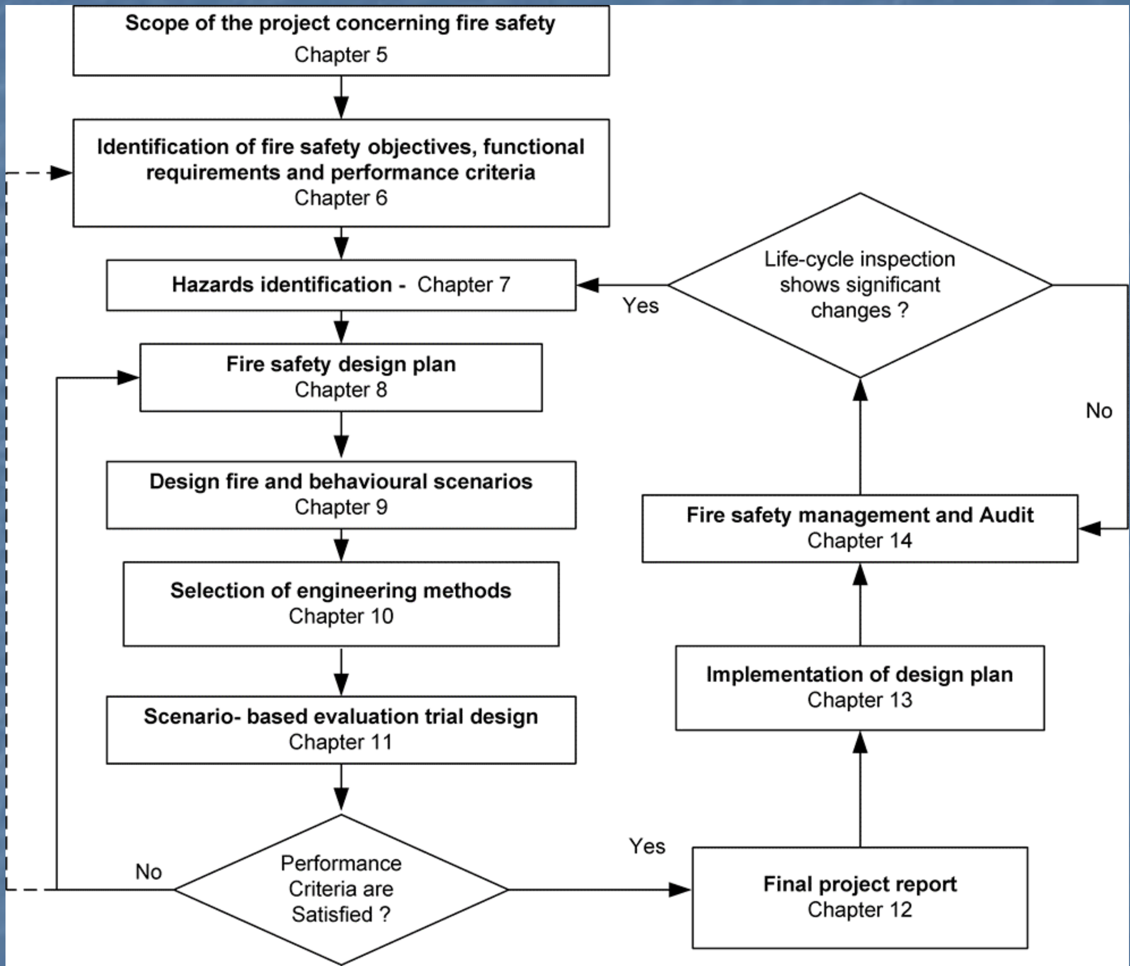
Plan for Session on Technical Methods

- General procedures for fire safety engineering
- Design fire scenarios & design fires
- Structural response & fire spread beyond enclosure of origin
- Fire calculation methods for fire initiation, movement, & impact on structures

Plan for Session – Cont'd

- Methods for assessing suitability of calculation methods for specific applications
- Verification & validation of fire calculation methods

Fire Safety Engineering Process



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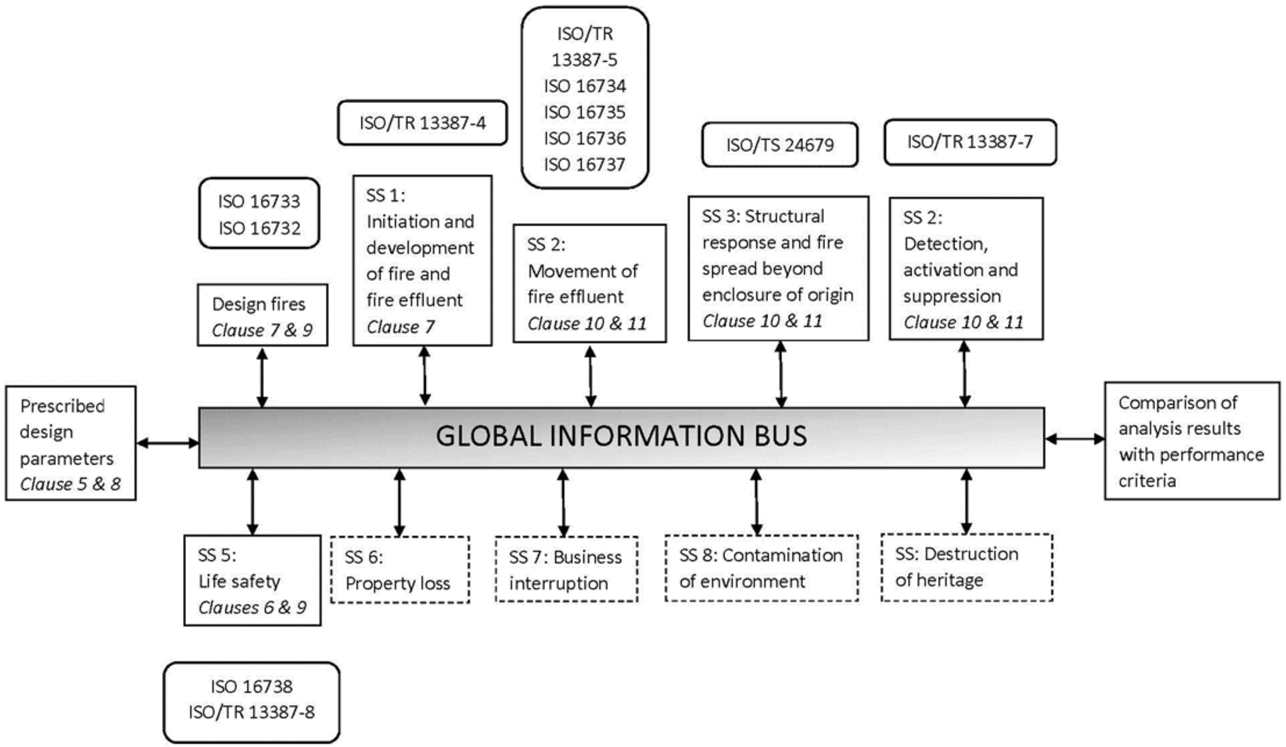
Safety Objectives

- Life safety
- Conservation of property
- Continuity of operations
- Preservation of heritage
- Protection of environment

Global Information Bus



Global Fire Safety Engineering Analysis and Information System

General Procedures for Fire Safety Engineering

- Contained in ISO 23932
- Provides procedures & requirements for a fire safety engineering design
- Standard under revision in ISO TC 92 SC 4
  - Link all SC 4 FSE standards to design process
  - Emphasize quality safety management & audit

Current Core FSE Standards

Chapter in ISO 23932	List of standards available	Comments
Scope of the project concerning fire safety – Chapter 5	-	Provided by architect to fire safety engineer
Identification of fire safety objectives, functional requirements and performance criteria – Chapter 6	ISO/NP 29761	The standards cover the life safety objective. Other safety objectives have not yet been elaborated.
Hazard Identification - Chapter 7 and Design scenarios – Chapter 9	ISO 16733, ISO 16732, ISO/NP 29761	ISO 16733 covers design scenarios generically, ISO 16732 includes risk methods for scenario selection, and ISO/NP 29761 covers the life safety objective.
Scenario based evaluation of trial design – Chapter 11	-	1. Covers fire plumes, smoke layers, ceiling jet flows, and vent flows, respectively.
1. Movement of fire effluents	ISO 16734, ISO 16735, ISO 16736, ISO 16737	
1. Structural response and fire beyond enclosure of origin	ISO/TS 24679-1	
1. Detection, activation, and suppression	ISO/TR 13387-7	
General to ISO 23932	ISO 16732-1, ISO 16730-1	ISO 16732-1 is used for a fire risk assessment approach. ISO 16730-1 is for verifying & validating methods used for Chapter 11.

Current Core FSE Standards

ISO 23932 *Fire Safety Engineering -- General Principles*

ISO/TS 16733:2006, *Fire safety engineering -- Selection of design fire scenarios and design fires.*

ISO 16732-1:2012, *Fire safety engineering -- Fire risk assessment -- Part 1: General.*

ISO 16734:2006, *Fire safety engineering -- Requirements governing algebraic equations -- Fire plumes.*

ISO 16735:2006, *Fire safety engineering -- Requirements governing algebraic equations -- Smoke layers.*

ISO 16736:2006, *Fire safety engineering -- Requirements governing algebraic equations -- Ceiling jet flows.*

ISO 16737:2012, *Fire safety engineering -- Requirements governing algebraic equations -- Vent flows.*

ISO/TS 24679:2011, *Fire safety engineering -- Performance of structures in fire.*

ISO/TR 13387-7:1999, *Fire safety engineering -- Part 7: Detection, activation and suppression.*

ISO/NP 16730-1, *Fire safety engineering -- Assessment, verification and validation of calculation methods -- Part 1: General.*

Scope of Project

- New built environment or modification of existing built environment
- Built environment includes buildings & other structures/systems, including tunnels, underground stations, etc.
- Application of FSE to limited section of built environment or whole part

Scope – Cont'd

- Design plan:
  - Purpose/function
  - Dimensions
  - Location of fixtures, furnishings, equipment
- Preliminary plan for new built environment or refurbishment project

Safety Objectives, Functional Requirements & Performance Criteria

- Objectives: what are required outcomes of foreseeable fires?
- Functional requirements: how outcomes achieved by design?
- Performance criteria: how adequacy of design measured?

Comparison with Prescriptive Regulations

- Prescriptive provide *"acceptable solutions"*
- Safety design *"deem to satisfy"*
- Derive mandatory objectives & functional requirements, or use intent of regulations
- Performance criteria can be relative to performance of *"acceptable solution"*

Examples

- Life safety objective: “occupants not intimate with fire will not be injured”
- Functional requirements for high rise building: “no design fire scenario should result in structural damage; or result in injury before evacuation for occupants not intimate with fire”

Examples – Cont’d

- Performance criteria: “quantitative criteria for structural fire resistance; & visibility & concentrations of narcotic & irritant gases before evacuation is completed”
- Performance criteria can be derived for prescriptive design requirements
- More examples later

Design Fire Scenarios & Design Fires

- Hazard identification:
  - Internal & external
  - Combustible materials
  - Natural hazards
- Use of fire incidence data
- Develop manageable group of fire scenarios to test fire safety system

Selection of Engineering Methods

- Algebraic equations
  - Quick & simple
  - Can provide conservative results
- Zone models
  - Appropriate for most applications
  - Provides average conditions
- CFD models
  - Use for specialized cases only

Scenario-Based Evaluation of Trial Design

- Development of input data
- Analysis of fire behavior
- Analysis of human behavior
- Determine if quantitative performance criteria are met for design fires
- Uncertainty of input data and analysis methods

Safety Factors & Uncertainty

- Sources of uncertainty
  - Choice of fire scenarios and design fires
  - Functioning of fire protection features
  - Predictive capability of fire calculation method
  - Input data for fire calculations
- Safety factors should consider uncertainty in overall analysis

Quality Safety Management – Conformity Assessment

- Develop final project report
- Conduct regulatory reviews & approvals from authorities
- Implement design plan
- Fire safety management & audit
- Life cycle inspection & reviews
- Importance of fire safety management

Examples of Safety Objectives, Functional Requirements & Performance Criteria

- France:
  - Safety Objective (OBJ): Health and life safety of occupants
  - Functional requirement (FNR)1: No sudden change in tenability conditions before evacuation from room of fire origin
  - FNR 2: Adequate tenability conditions in the egress route

OBJ, FNR, PR - France

  - FNR 3: Adequate tenability conditions in waiting area within the building
  - FNR 4: Adequate tenability conditions in place of refuge
- Performance criteria (PR) for FNR 1-4
  - Criteria 1: Maximum gas temperature of 60°C (references given)
  - Criteria 2: Maximum incident heat flux of 2 kW/m^2

OBJ, FNR, PR - France

- Criteria 3 :Maximum radiative dose of 3 ? kW per m*2
- Criteria 4: Maximum Fractional Effective Dose (FED) of 0.3
- Criteria 5: Minimum visibility of 10 m (as calculated within ISO 13571)

OBJ, FNR, PR - New Zealand

- Systematic review conducted over several years lead to performance-based Building Code & Verification Method C/VM2
- New Building Code (2012) specifies safety objectives (OBJ), functional requirements (FNR) & performance criteria (PR)

OBJ, FNR, & PR – New Zealand

- OBJ: safeguard people from unacceptable risk of injury or illness caused by fire
- Clauses provide FNRs & PRs for:
  - C2: Prevention of fire:
    - FNR: Fixed appliances using controlled combustion must be designed in a way that reduces likelihood of illness or injury due to fire occurring
    - PR e.g. Maximum surface temp. of combustible building materials near appliances< 90°C

OBJ, FNR, PR – New Zealand

- C-3: Fire affecting areas beyond fire source – covers flame spread & specifies material performance (PRs) determined by standard tests (e.g. ISO tests)
- C-4: Movement to place of safety: Buildings must provide means of escape so probability of occupants suffering injury is low (FNR) (performance-based design)

OBJ, FNR, PR – New Zealand

- Evacuation should occur such that occupants not exposed to (PRs):
  - FED of CO > 0.3
  - FED of thermal effects > 0.3
  - Visibility < 10 m
- Above can be calculated with fire calculation methods

OBJ, FNR, PR – New Zealand

- C5: Fire fighter operations
- C6: Structural stability
- Verification method C/VM2 provides details on conduct of fire modeling for design fires:
  - Obtain uniformity in application for fire safety
  - Provides means for conformity assessment

OBJ, FNR, PR - Japan

- Prescriptive standards prescribe acceptable solutions in terms of permissible materials, structures fire resistance ratings, equipment designs, dimensions of spaces
- Development of the Comprehensive Fire Safety Design Method of Buildings – 1986
  - Identified OBJ, FNR of prescriptive regulations

OBJ, FNR, PR - Japan

- Equivalency concept for PB design
- Technical standards (PRs) provide numerical values or formulas to facilitate conformity assessment without ambiguity
- Included in Building Standards Law (BSL)

- OBJ 1: Prevention of Fire Occurrence
- OBJ 2: Exclusion of Hazardous Materials
- OBJ 3: Assurance of Life Safety

OBJ, FNR, PR - Japan

- OBJ 4: Assurance of The Third Parties' Property
- OBJ 5: Assurance of Fire Brigade Operation
- Predictive calculation methods for fire behavior specified in BSL
  - Simple & conservative

OBJ, FNR, PR - Japan

  - PRs: Numerical values contained in BSL
- OBJ 3: Assurance of Life Safety - ensure safety from fire for the entire occupants
  - FNRs: Evacuation plans
  - FNRs: Limitation of hazardous materials
  - FNRs: Assurance of safe refuge: *Evacuees shall be free from danger due to fire, smoke, flame, radiant heat, damage or collapse of the building*

OBJ, FNR, PR - Japan

- FNRs: Assurance of safe evacuation route: *evacuation route shall be free from fire hazards, smoke, flame, radiant heat, collapse and breakage etc.*

OBJ, FNR, PR - Japan

- Formulas used which include performance criteria (PRs) to verify compliance:
  - Smoke - indoor & outdoor
  - Radiant heat
  - Falling debris
  - Structural stability
  - Fire spread to other buildings
- Transparent approach

OBJ, FNR, PR
Recommended Approach

- Develop OBJ which are qualitative & contain policy and societal goals
- Develop FNR as more detailed statements that can specify certain requirements
  - Implemented as prescriptive requirements; e.g. material test specifications
  - Through performance-based analysis, e.g., evacuation analysis

OBJ, FNR, PR Recommended Approach

- Develop PR which determine if functional requirements are met
- Include OBJ, & FNR in law & regulations as mandatory requirements
- Include PR, calculation methods & input data as part of verification method

Design Fire Scenarios & Design Fires – ISO 16733-1

- Step 1: Establish design fire scenarios for a specific objective
  - Life safety, property loss, heritage
  - Describes sequence of events & conditions
- Step 2: Establish design fires for that objective
  - Defines specific heat release rate

Design Fire Scenarios – Options for Development

- I - Prescribed scenarios for built environment and safety objective
- II – Qualitative approach
- III – Quantitative & risk-based approach

Design Fire Scenarios – Qualitative Approach

- Identify safety objective & challenges
  - Type of built environment
  - Safety challenge
- Location of fire
  - Fire statistics
  - Experience

Design Fire Scenarios – Qualitative Approach

- Type of fire
  - Ignition source
  - Growth of fire
- Complicating hazards
  - Common cause events, e.g. earthquakes
  - High hazard materials

Design Fire Scenarios – Qualitative Approach

- Systems interactions
  - Passive systems, e.g. doors
  - Active systems, e.g. suppression systems
- Occupant actions
- Initial selection
- Modification based on system unavailability
- Final selection

Design Fire Scenarios – Example from New Zealand Building Code

- Fire blocks exit
- Fire in normally unoccupied room threatens occupants in other rooms
  - ASET/RSET analysis or provide separation
- Fires in concealed spaces
  - Provide separation

Design Fire Scenarios – Example from New Zealand Building Code

- Smoldering fire
  - Provide automatic detection & alarm
- Fire spread in internal linings
  - Use suitable materials proven by tests
- Challenging fire for evacuation & life safety
  - ASET/RSET analysis

Design Fire Scenarios – Example from New Zealand Building Code

- Robustness check
  - ASET/RSET analysis assuming fire safety system unavailable
- Horizontal fire spread to other buildings
  - Radiation calculation
- External vertical fire spread
  - Use suitable materials proven by tests

Design Fires – Example from Swedish Building Regulation

Fire Scenario	Occupancy	Growth rate	HRR (MW)	Heat of Combustion (MJ/kg)
1 & 2	Office/School	Medium	5.0	16
1 & 2	Dwellings, hotels & healthcare facilities	Fast	5.0	20
1 & 2	Assembly halls	Fast	10.0	20
3	All occupancies	Fast	2.0	20
1 = high stress scenario	2 = Hidden fire	3 = Robustness scenario		

Design Fires – Example from Swedish Building Regulation

Fire scenario	Soot production	CO production (g/g)	CO2 production (g/g)
1 & 2	0.10	0.10	2.5
3	0.06	0.06	2.5

Design Fires – Recommended Approach

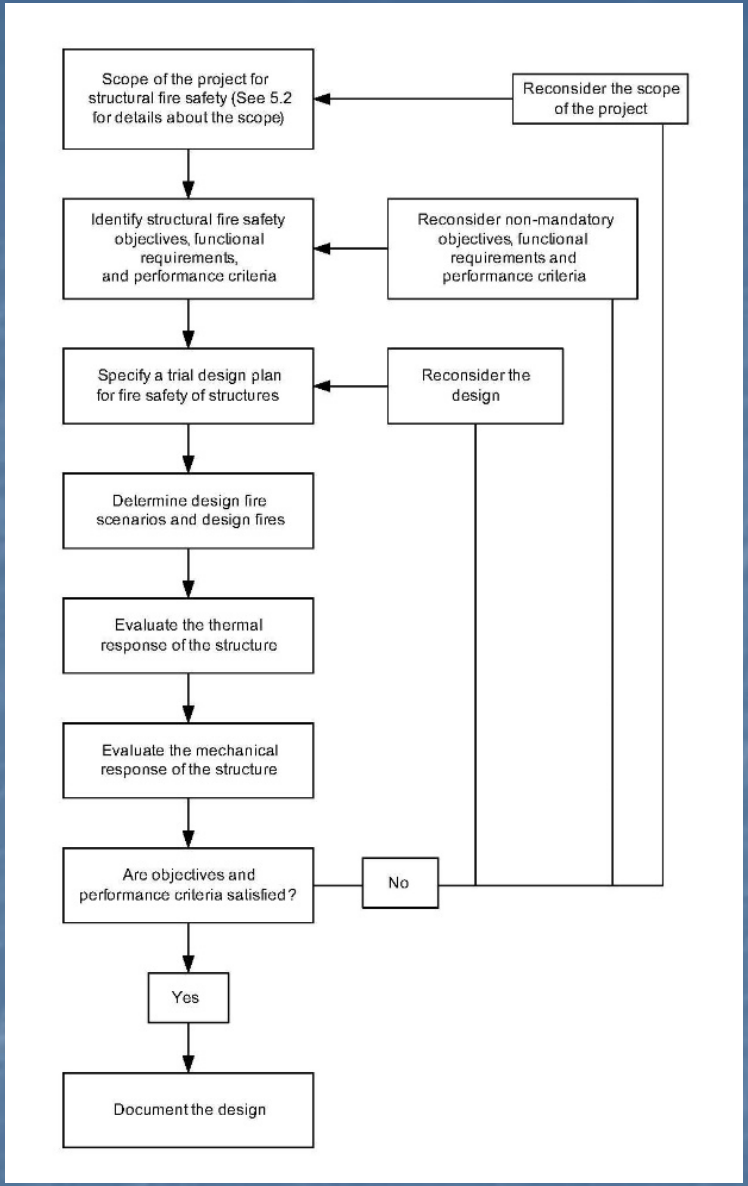
- Develop prescribed design fire fires for specific types of built environment & safety objectives, & include in regulation
- Design fires will then be fixed for use by designers in different projects

Structural Response & Fire Spread

- ISO/TS 24679: Performance of structures in fire
  - Thermal response of structures & boundaries
  - Mechanical response of boundaries
  - Fire spread
  - Structural collapse

Structural Response & Fire Spread

- Prescriptive regulation
  - Fire *resistance* tests for single fire & isolated elements & assemblies determine acceptability
- Performance-based design
  - Analyze real fires
  - Examine behavior of whole structural system
  - Consider realistic loads & cooling phase



From ISO/TS 24679:2011

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Structural Response & Fire Spread - FNR

- Functional requirements stated in terms of compartmentation, integrity & stability
  - Compartmentation
    - Prevent or limit fire spread within & outside built environment
    - Maintain integrity of separating elements
  - Integrity & stability of structure
    - Prevent failure
    - Limit deformation

Structural Response & Fire Spread - PR

- Limit harm due to fire spreading
  - Criterion for limiting heat transfer, thermal radiation to materials in non-fire room
  - Criterion to limit spread of hot gases, e.g. leakage rate to non-fire room
- Limit harm due to collapse of structure
  - Criterion for load bearing elements
  - Criterion for critical elements
  - Criterion for progressive & global failure

Structural Response & Fire Spread

- Calculation methods:
  - Simple formulas (Japan)
  - One-zone model for flashover conditions
  - Two-zone models
  - CFD models
- Thermal calculations:
  - Heat transfer from hot gases
  - Heat transfer within element (conduction)

Structural Response & Fire Spread

- Mechanical response – Assess:
  - Load bearing capacity
  - Deformation of structure
- Representation options:
  - Temp. dependent/thermal expansion between elements
  - Temp. independent/expansion within element

Structural Response & Fire Spread

- Required input data for calculations:
  - Thermal properties:
    - Specific heat, thermal conductivity, density, moisture content
  - Mechanical response:
    - Stress-strain relationship
    - Expansion or contraction at high temp.
- Consideration of uncertainties important

Structural Response & Fire Spread

- Limited number of validated calculation methods
- Limited capability to model some phenomena, e.g. spalling
- Lack of thermal properties at elevated temperatures

Structural Response & Fire Spread Recommended Approach

- Use of simple formulas and performance criteria have an advantage
- Examine and validate calculation methods for thermal & mechanical response
- Conduct tests to gain:
  - Further understanding of phenomena
  - Develop & validate calculation methods

Questions

- Comments and discussion
- Thank you

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