Tunnel Fire Modeling and Concrete Lining Protection

CSIRO

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Presentation Format

Presentation in two parts

- Tunnel fire modeling - Dr Vivek Apte
- Composites for tunnel lining - Dr Radhe Khatri

Part 1

Tunnel Fire Modeling

Presentation Objectives

- Identify major issues related to tunnel fire safety
- What are the gaps in information?
- CSIRO research focus
- Outline of some CSIRO research activities

Tunnel Fire Safety Issues

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In the event of a major tunnel fire:

- Ventilation system for smoke control
- Evacuation strategies for people
- Fire suppression and control strategies
- Protection of concrete lining

Gaps in Information

How BIG is a Fire? – a big unknown

In the event of a major tunnel fire:

- How does the fire develop?
- What is the fire size profile?
- How does this affect people safety?
- What is the impact on the tunnel structure?

CSIRO Fire Science Research Focus

CSIRO research program includes:

- Quantify fire size (MW) – Credible ***Design Fire***
- Better inputs to CFD fire models
- Well-instrumented real-scale and large-scale experiments to validate & calibrate CFD fire models
- Tunnel lining fire protection
- Applications in fire engineering

Key Research Objective

- Define/ quantify **Credible Design fire**, i.e., heat release rate profile from a fire in a tunnel

This is a vital input to tunnel fire safety design

Example: fire in a train, bus or a heavy goods vehicle

Real-Scale Fire Experiment - 1

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Example - Fire in a Train Compartment

Objectives

- Effect of ignition source size on fire growth
- Understand fire growth and smoke spread
- Link fire performance of materials and components in the compartment with fire size
- Use data in conjunction with CFD fire models to estimate the fire size

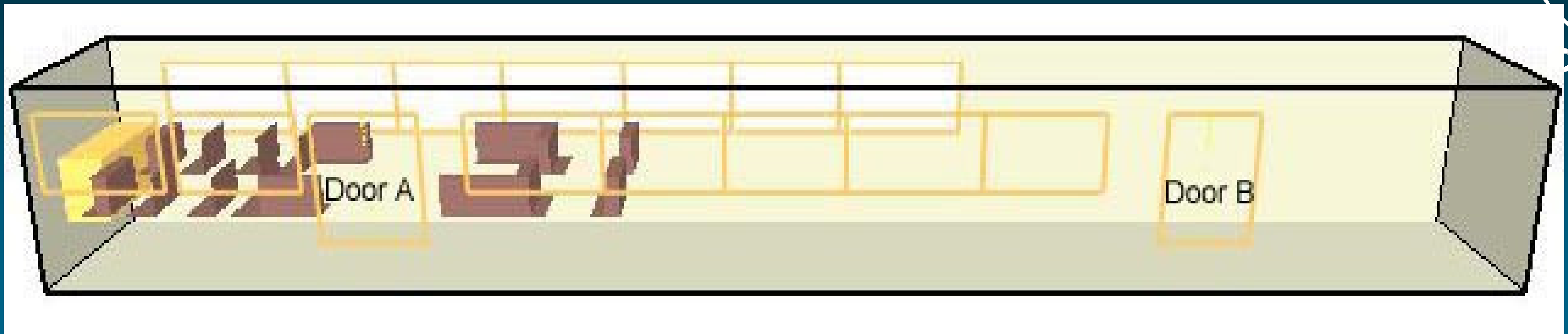
Real-Scale Fire Experiment - 2

- Urban passenger train
- Measurements
  - Thermocouples
  - Radiometers
  - Air flow through door
  - Video
  - Materials flammability properties
- Heat release rate not measured

Real-Scale Fire Experiment - 3

- Ignition using a pile of crumpled newspaper, timber crib etc.
- Similar experiment can be conducted in a bus, a lorry etc

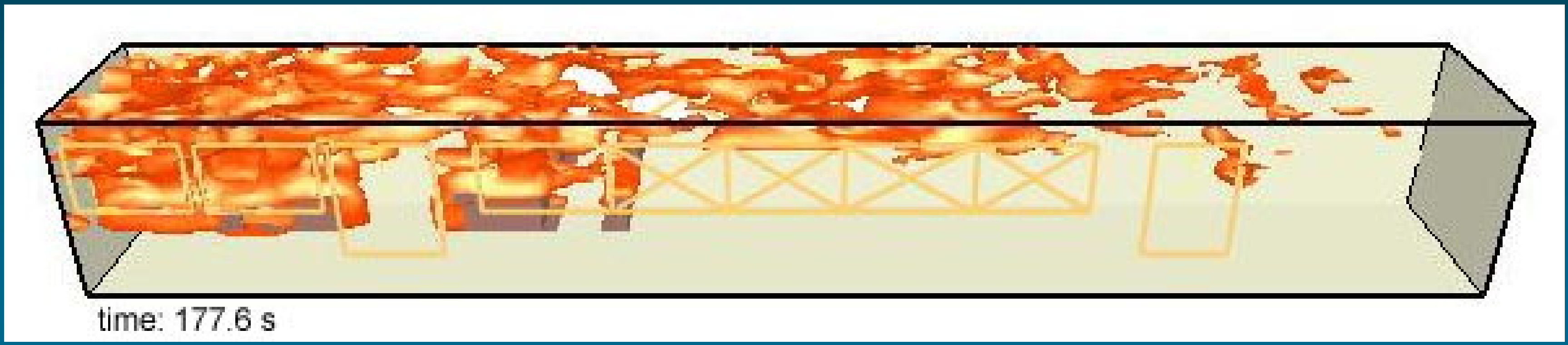
CFD Fire Model Input



Example: fire in a train compartment

- Compartment geometry
- Doors, windows
- Seats arrangement, number
- Floor, wall and ceiling linings
- Material properties
- Ignition source heat release rate

CFD Fire Model Output



Example: fire in a train compartment

- Ignition of materials, components
- Fire and smoke development
- Temperature field – variation with time and space
- Smoke spread – function of time and space

Heat Release Rate Prediction in a Tunnel

- Calibration of a CFD fire model
  - Well-instrumented enclosure fire experiment
  - Measure heat release rate and temperatures
  - Back-calculate heat release rate from measured temperature
- Use calibrated CFD model and temperatures measured in a real-scale train fire experiment to back-calculate heat release rate in the train. This is the design fire
- Input this design fire to a CFD fire model for a tunnel situation to calculate fire and smoke development in the tunnel.

Concluding Remarks

CSIRO Research

- **Quantify heat release rate from a fire, i.e., a design fire in a tunnel using**
  - **CFD fire models, calibrated against enclosure fire experiments**
  - **Real Scale Fire Experiments (e.g. in a train) to validate the model**

Input the design fire to a CFD model to compute

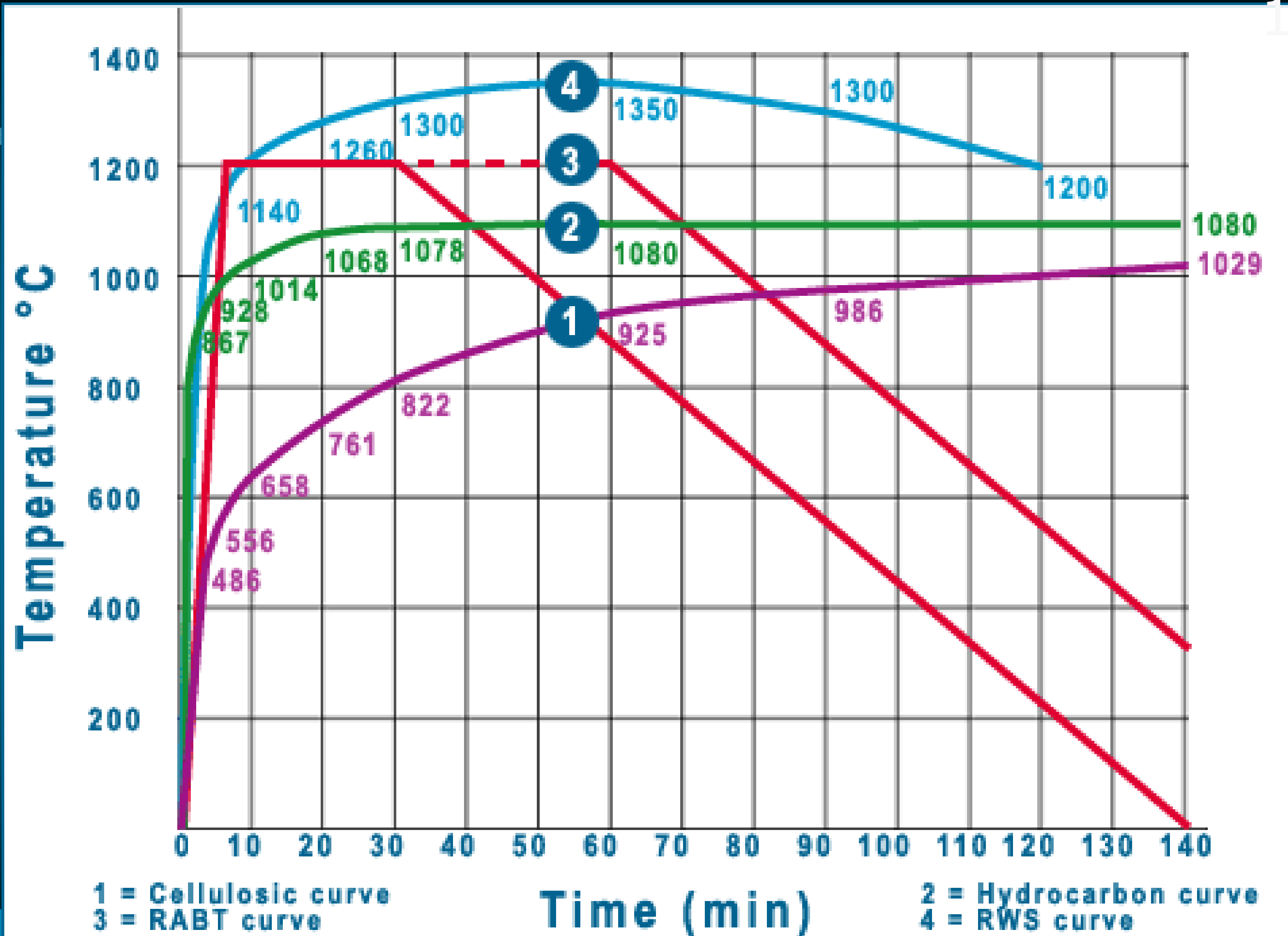
- **Temperature distribution in the tunnel**
- **Smoke spread patterns in the tunnel**

Part 2

Hydrocarbon Fire Resistant Composites for Tunnel Lining

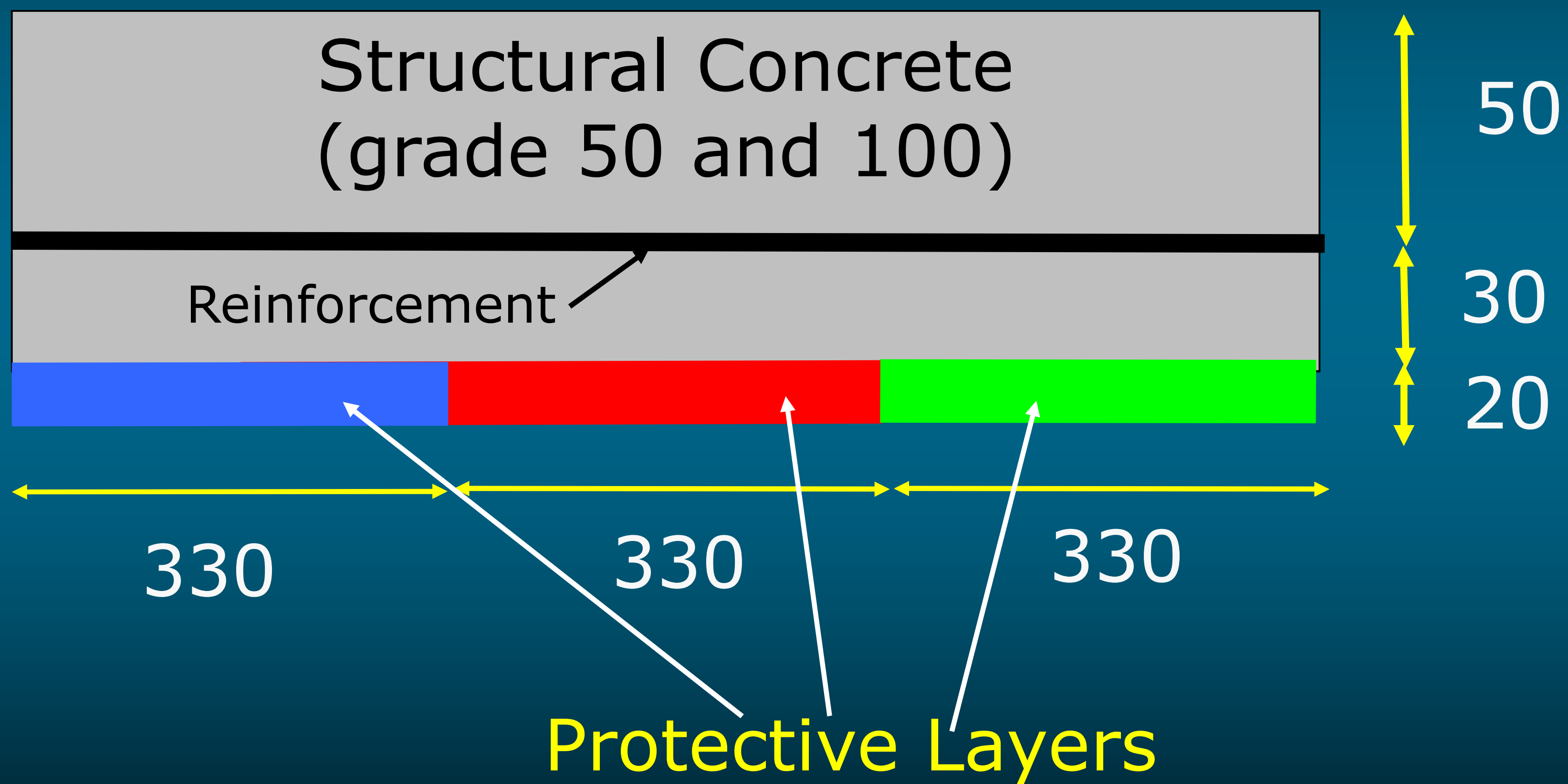
What is a Hydrocarbon Fire ?

- Hydrocarbon Fire
  - Fires produced by hydrocarbon fuels
  - Tunnels are susceptible as trucks carrying hydrocarbon fuels & other combustible materials are transported through them
- Impact of HC fire (*Khoury, 2000*)
  - Channel Tunnel Fire, 1996: Temp reached 700°C, 400mm thick concrete lining reduced to 20mm. Tunnel closed for 6 months & loss of US$1.5 million per day
  - Mont Blanc Tunnel Fire, 1999: 53 hrs burning, 39 deaths, 23 trucks & 11 cars destroyed
  - St. Gotthard Tunnel Fire, 2001: 11 deaths, roof collapsed and tunnel closed for 2 months

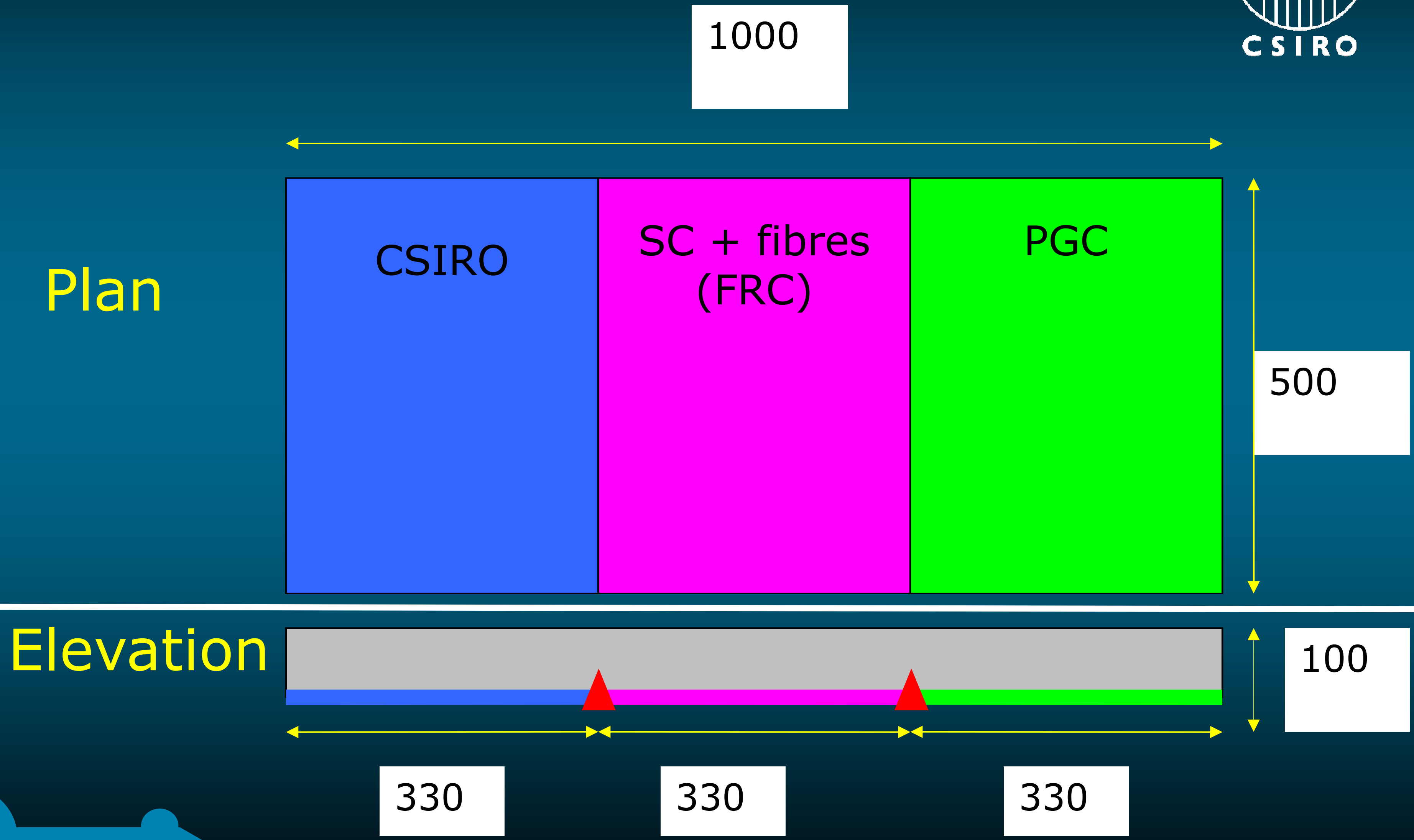

Temperature °C
1400
1200
1000
800
600
400
200
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140
Time (min)
4
3
2
1
1300
1350
1300
1260
1200
1140
1080
1068
1078
1080
1014
928
867
1029
986
925
822
761
658
556
486
1 = Cellulosic curve
3 = RABT curve
2 = Hydrocarbon curve
4 = RWS curve

Specimen Configuration

Elevation



Specimen Configuration

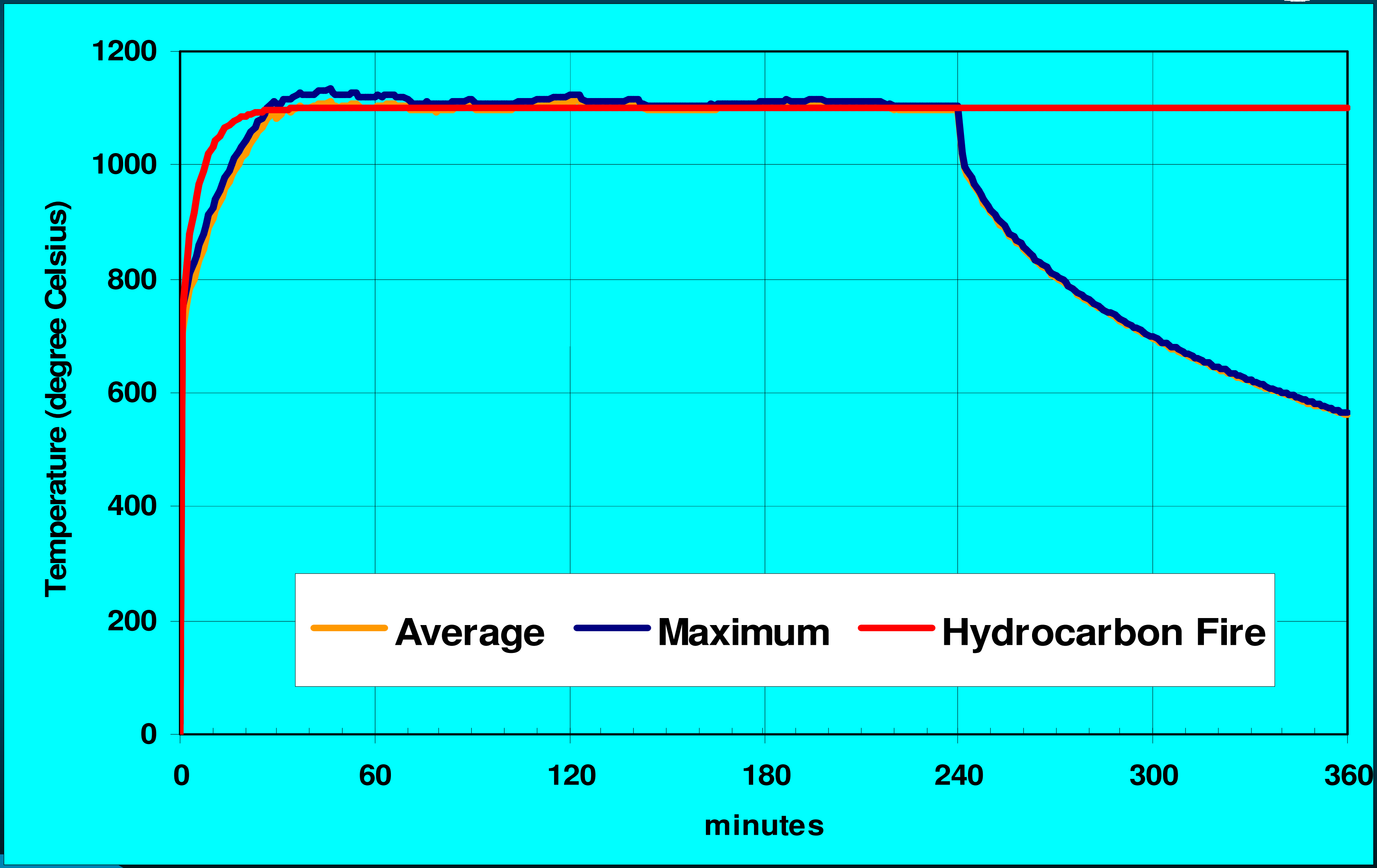


Details of Protective Layers

- A polypropylene Fibre Reinforced Concrete (FRC)
- A Porous Grade Concrete (PGC) (nominally grade 10), and
- A CMIT developed heat resistant product (CSIRO).

Exposure to Hydrocarbon Fire

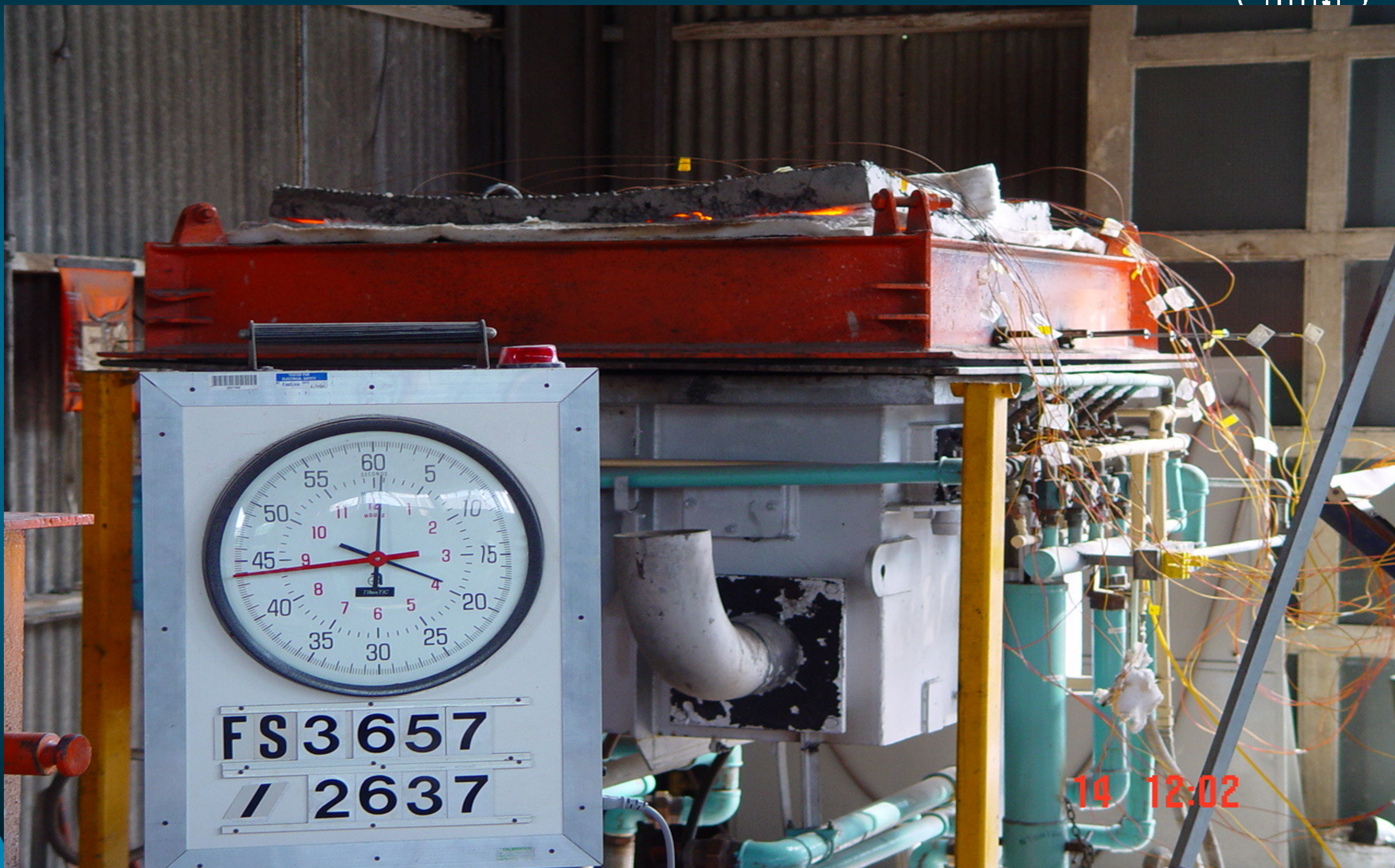
Comparison of Temperature Profiles



Exposure to Hydrocarbon Fire

- Four hours of hydrocarbon fire with maximum temperature reached was 1100°C.
- Slabs subjected to fire load only (stress free)

Exposure to Hydrocarbon Fire



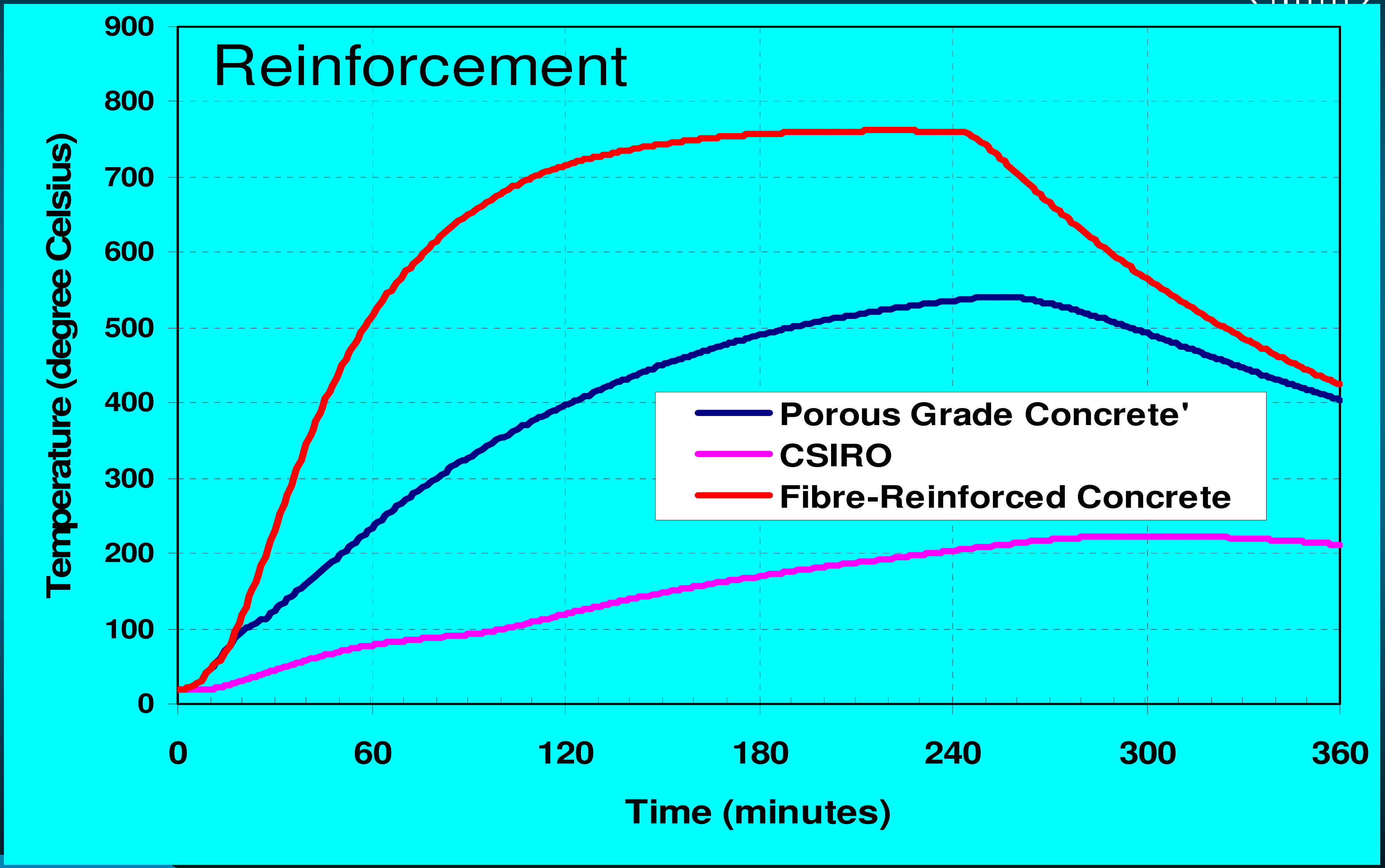
Performance of Composites

- Effect of fire on the bond between the protective layer and the high strength structural concrete
- Extent of spalling of protective layer and the structural concrete
- Temperature reached at various depths of structural concrete (extent of protection to the structural concrete)

Samples After the Test

Samples After the Test

Temp. Profile at the Reinforcement



Assessment of Damage

Properties Studied

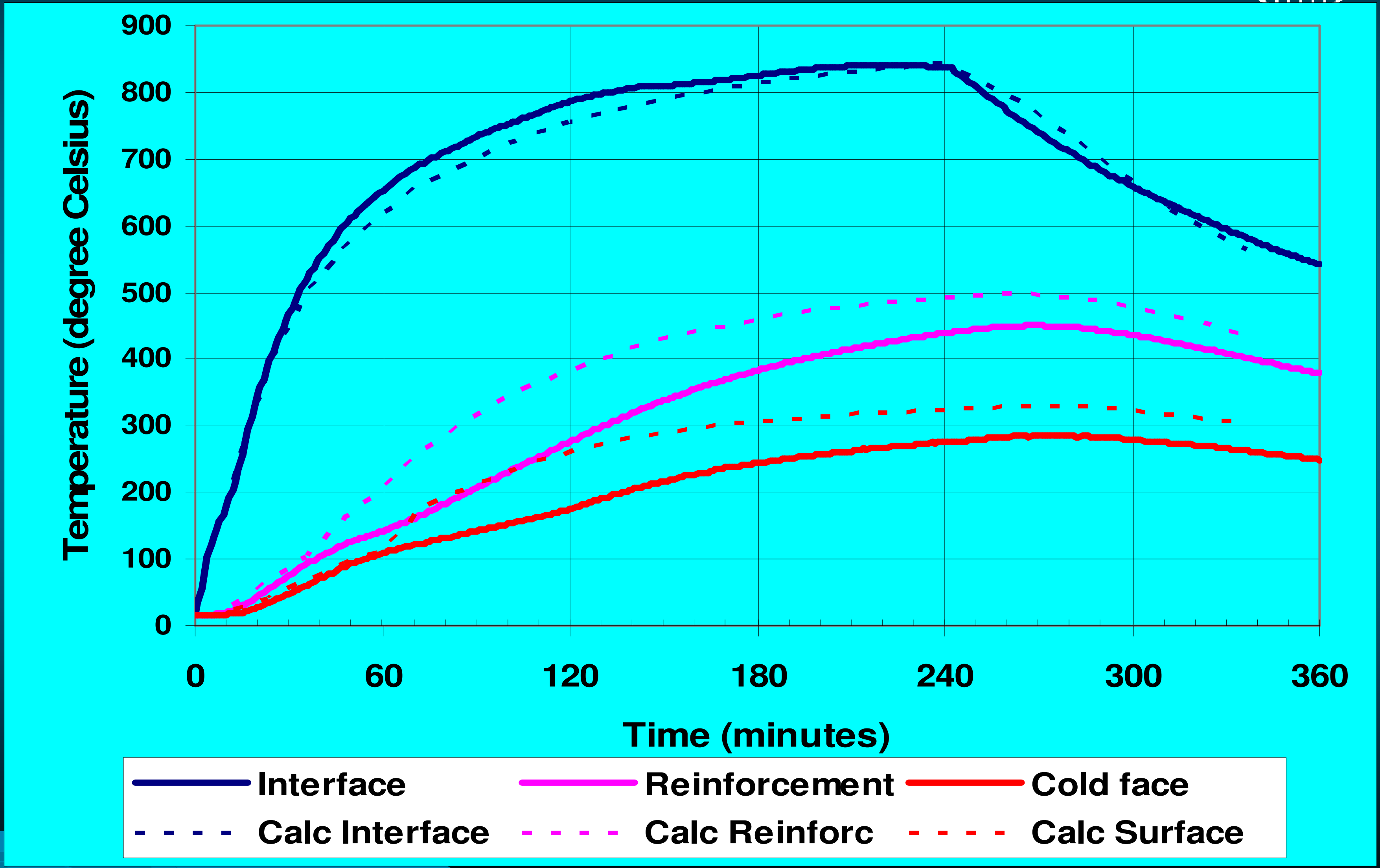
- Strength loss
- Changes in microstructure
  - Deterioration of pore Structure
  - Chemical (phase) changes

Assessment of Damage

Techniques used

- Mercury intrusion porosimeter
- Volume of permeable voids
- Differential thermal analysis
- Schmidt hammer
- Scanning electron microscopy – elemental analysis

Modelling of Temperature profile



Modelling of Temperature profile

- Temperature profiles predicted using finite element method
- Temperature profiles can be established for other fire curves established by the Fire Research Group
- Critical material parameters can be established
- A material can be engineered for the desired "thermal characteristics"

Conclusions

- CSIRO research focuses on quantifying the **design fire**, i.e., **heat release rate from a major fire** in a tunnel using calibrated CFD fire models, validated against real-scale fire experiments. A design fire is a key input to fire safety design of tunnels.

- Composite developed at CSIRO can successfully protect the high-strength concrete against hydrocarbon fire. The damage to structural concrete evaluated by various techniques was found to be minimal. With temperature modelling the performance in other types of fire can be also evaluated.

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