Investigation on fire detection technologies for road tunnels

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https://doi.org/10.4224/21274145

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Investigation on Fire Detection Technologies for Road Tunnels

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National Research Council Canada | Conseil national de recherches Canada | Canada

Background

- Fires in tunnels significant risk to life and property
  - •High direct costs
    - Deaths and injuries;
    - Damage to tunnel structure and facilities.
  - •Indirect costs
    - Significant economic and political impact.

Tunnel Detection Project

- Tunnel fire detection project.
  - Initiated in 1999 at the request of Port Authority of New York and New Jersey and Boston Fire Department.
  - Phase I – literature review was completed in 2003.
- Phase II –Initiated in 2006.
  - Funded private and government sector organizations.
  - Monitored by Technical Advisory Committee.

Project Objectives

- Investigate performance of current fire detection technologies (detection capability and reliability).
- Provide information for developing technical specifications and installation requirements of detection systems for road tunnel applications.
- Provide technical data to standards and code writers for the development of guidelines for applications of fire detection technologies in road tunnel.

Project Tasks

- NRC
  - Task 1 - Identify technologies and develop test protocols.
  - Task 2 - Conduct fire tests in a laboratory tunnel facility.
  - Task 3 - Computer modeling.
  - Task 4 - Conduct fire tests in tunnel in Montreal.
  - Task 7 - Conduct fire tests in laboratory facility with longitudinal airflow.
- Hughes Associates
  - Task 5 - Conduct environmental tests in Lincoln Tunnel.
  - Task 6 - Conduct demonstration fire tests in Lincoln tunnel.

Current Tunnel Detection Technologies

- Linear heat detection systems and optical flame detectors the primary methods of detecting fires in tunnels.
- Information on tunnel detection technologies limited.
  - Few detection technologies investigated.
  - Performance realistic fire scenarios unknown.
  - Information on reliability in tunnel environment is limited.
- Lack of application guidelines for detection systems.
  - Lack of appropriate test protocols/standards for evaluation.
  - Lack of technical information in standards/codes for performance requirements and installation.

Detection Systems

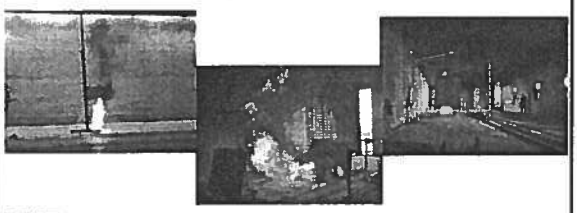
Technology	System No.	System Information
Linear heat	D-1L1	Fiber optic linear heat detection system
	D-2L2	Analogue (co-axial cable) linear heat detection system
Flame	D-3F1	Multi-IR flame detector
VID	D-4C1	Visual based flame/smoke detector
	D-5C2	Visual based flame/smoke detector
	D-6C3	Visual based flame detector
Spot heat	D-7H1	Frangible bulb heat detector
	D-8H2	Rate-anticipation heat detector
Smoke	D-9S1	Air sampling system

Detector Performance

- Detection capability.
  - Response time.
  - Locating fire.
  - Monitoring fire development.
- Detection reliability.
  - Reliable in detecting a fire – low false alarm rate.
  - Reliable in working in harsh environment – limited maintenance requirements.

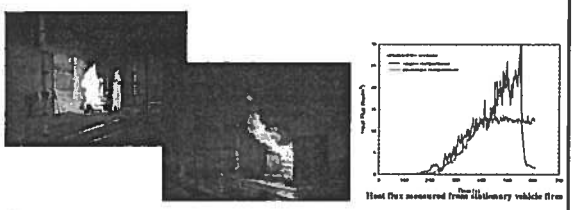
Pool Fires

- Pool fires - fast growing fires (gasoline, propane)
  - Small open fires (125 kW);
  - Fires underneath the vehicle (125 ~ 3400 kW);
  - Fires behind a large vehicle (650 ~ 3400 kW).



Stationary Vehicle Fires

- Slow growing fires.
  - Engine compartment fires – gasoline (~2000 kW)
  - Passenger compartment fires – wood crib/polyurethane foam (~1500 kW).

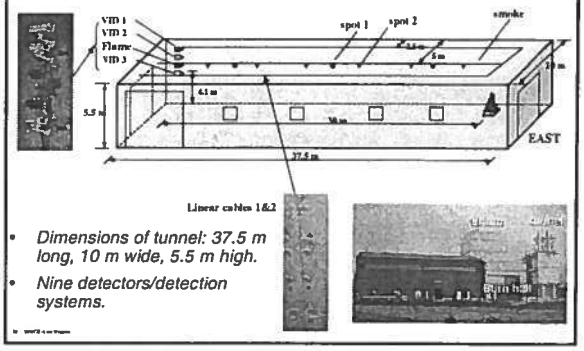


Heat flux measured from stationary vehicle fires

Moving Vehicle Fire

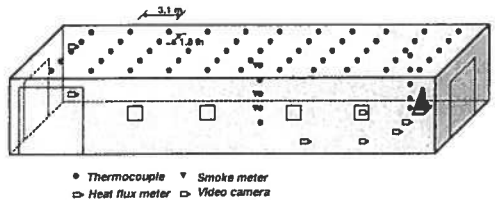
- Fast moving fires (~150 kW).
  - Fires with two driving directions towards and away from detectors.
  - Two speeds: 25 km/h, 50 km/h.

Tunnel Facility



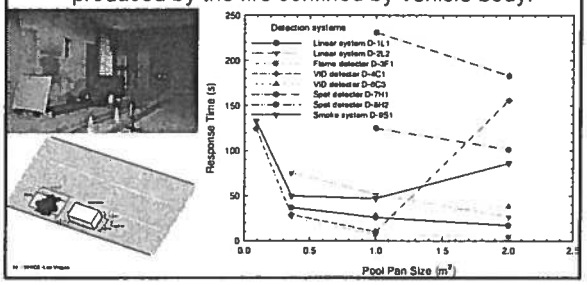
- *Dimensions of tunnel: 37.5 m long, 10 m wide, 5.5 m high.*
- *Nine detectors/detection systems.*

Instrumentation



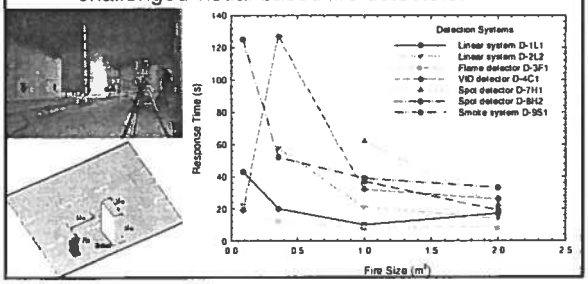
Pool Fires Underneath a Vehicle

- Pool fires underneath vehicle challenged all detection systems, as the flame and heat produced by the fire confined by vehicle body.

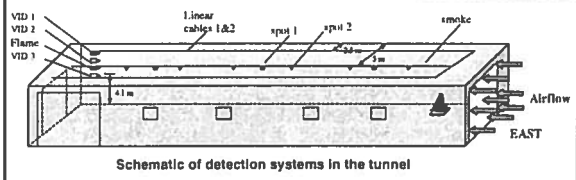


Fire Behind a Vehicle

- Simulated vehicle did not affect performance of heat and smoke detection systems but challenged visual-based fire detectors.



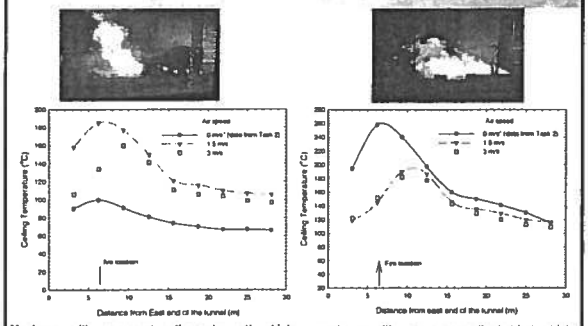
Longitudinal Airflow



Schematic of detection systems in the tunnel

- *Fire detectors faced opening.*
- *The airflow was toward detectors.*
- *Three air velocities: 0 m/s, 1.5 m/s, 3 m/s.*

Effect of Airflow on Temperature

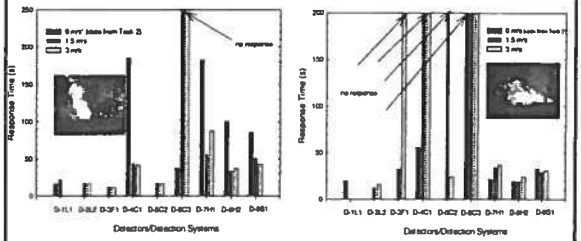


Maximum ceiling temperature fire underneath vehicle

Maximum ceiling temperature fire behind vehicle

Detector Response with Airflow

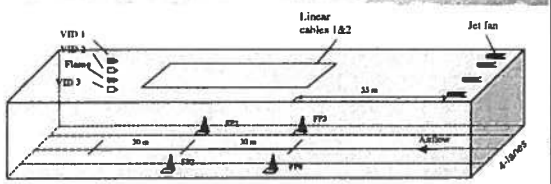
- Reduced response time for fires under vehicle
- Increased response time for fires behind a vehicle



Response times pool fire under vehicle

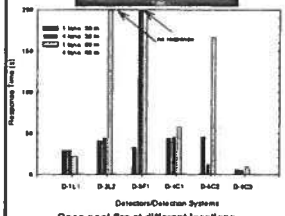
Response times pool fire behind vehicle

Tests in Montreal Tunnel

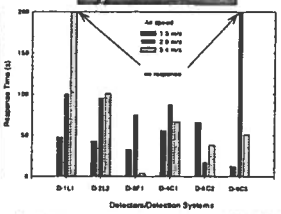


- Dimensions: 400 m long, 16.8 m wide (4 lanes), 5 m high;
- Four jet fans in tunnel;
- Six detectors/detection systems;
- Fire at four locations

Detector Response



Open pool fire at different locations



Pool fire underneath vehicle at different airflow speeds

Results Montreal Tests

- Results generally consistent with the laboratory tunnel tests under the same test conditions.
- Linear heat detection systems detected small fires regardless fire location.
- Airflow delayed response.
- Flame detector detected fires at its detection range (~30 m). Response time depended on airflow.

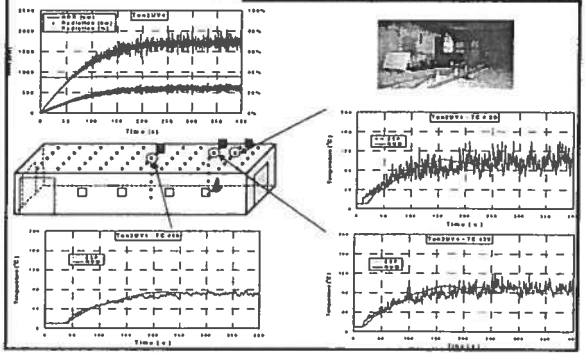
Results Montreal Tests

- VIDs detected small open pool fires within their detection range (~60 m).
- Detection time affected by airflow for fires underneath vehicle.
- VIDs detected fire behind vehicle 30 m from detectors.
- Two VIDs did not detect fire behind vehicle located 60 m from detectors.

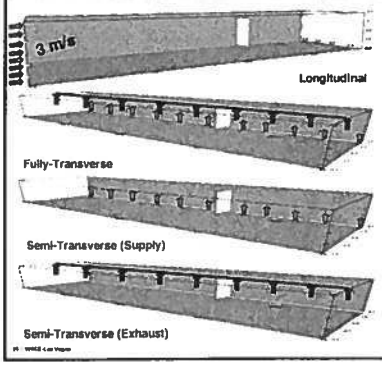
CFD Simulations

- Assist in the preparation of full-scale experiments conducted in the laboratory tunnel facility.
- Compare numerical predictions against the full-scale experimental data.
- Investigate the impact of tunnel ventilation conditions (longitudinal, semi-transverse and fully-transverse ventilation systems) on the development and distribution of the temperature and smoke.
- Study the impact of tunnel length on the development and distribution of temperature and smoke in the tunnel.

Comparison Experimental Results

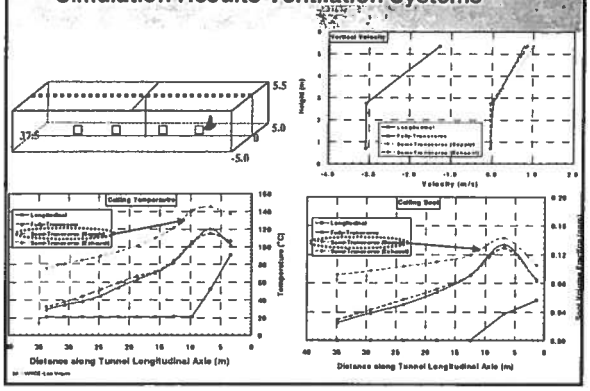


Ventilation Systems

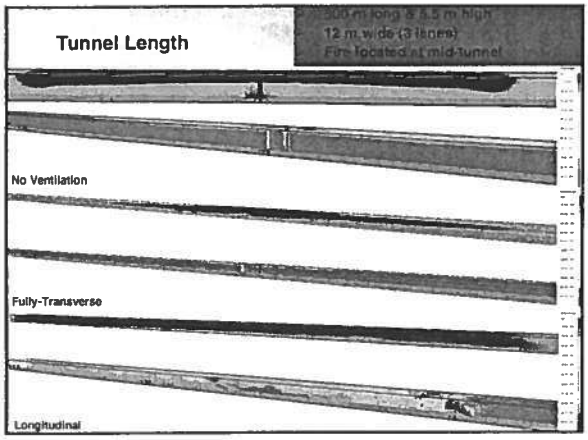


- 37.5 m long
- 10 m wide
- 5.5 m high

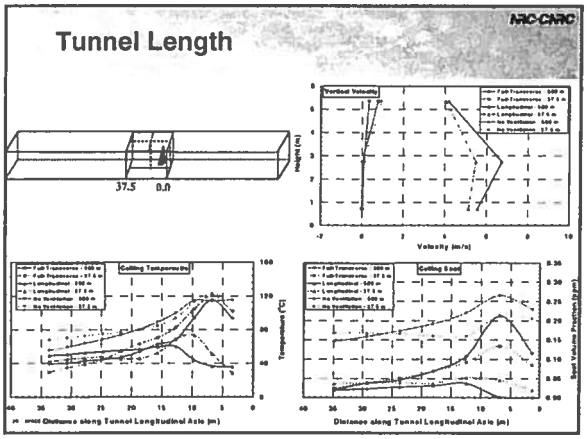
Simulation Results Ventilation Systems



Tunnel Length



Tunnel Length

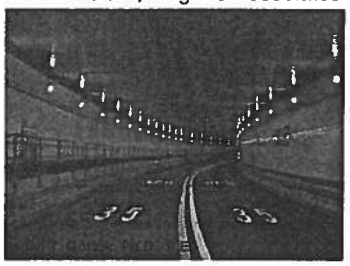


Summary Modeling

- Good agreement numerical simulations and experimental.
- Semi-transverse supply ventilation system.
  - Highest ceiling temperature and soot volume fraction.
  - Fastest rate of rise of ceiling temperature.
- Full- and semi-transverse exhaust systems.
  - Similar hot layer temperatures and soot profiles .
  - Semi-transverse exhaust system slowest rate of rise of temperature.
- Longitudinal system.
  - Lowest average ceiling temperature.
  - Require detectors downstream of the fire to detect the fire.
- Length of Tunnel.
  - Ceiling temperature and soot volume fraction profiles for the two tunnel lengths were similar.

Lincoln Tunnel Fire Detection Evaluation Program

- Dan Gottuk, Hughes Associates



Lincoln Tunnel – South Tube

- 2441 m (8006 ft) long.
- Roadway section is 6.6 m (21.5 ft) wide and 4.15 m (13 ft 7.5 in) high.
- Eastbound traffic only (NJ to NY).
- All vehicle types.
- Average daily traffic volume ~44 thousand vehicles.
- Slow moving and stopped traffic frequently occur.
- Transverse ventilation.

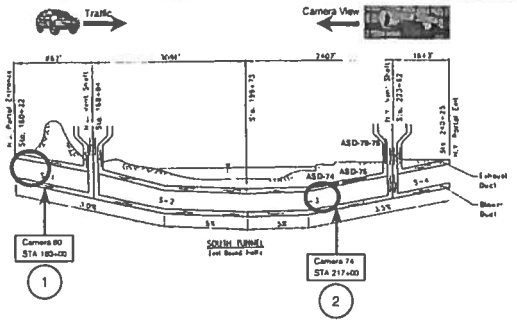
Program Overview

- Long-term monitoring of fire detection systems.
- Evaluation of 3 fire detection technologies.
  - Video Image Detection (VID).
  - Optical Flame Detection (OFD).
  - Smoke Aspiration Detection.
- 4 Detection systems installed and monitored.
- Fire Demonstration Tests.

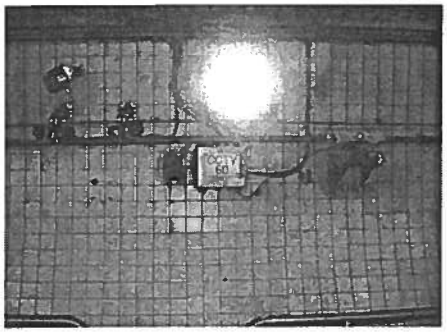
Detection Systems

ID	Technology	System Information	Hardware Location
D-3F1	OFD	Flame	Roadway
D-4C1	VID	Smoke and Flame	Tunnel Cameras with Unit in Administration Building
D-6C3	VID	Flame	Roadway
D-9S1	ASD	Smoke	Exhaust plenum

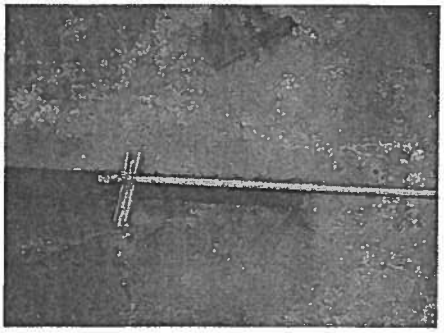
Detector Locations



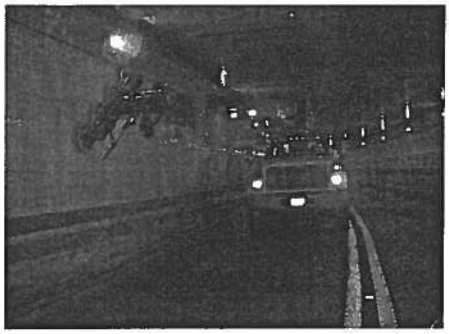
Detectors at Camera 60



Air Vent Sampling Point



Wet Environment



Data

- Data collected over 10 month period.
- Recording.
  - Events (date and time).
  - Weather conditions (sun/clouds/rain, T, RH).
  - Ventilation.
  - CO levels.
- Traffic data.

Results Environmental Tests

- VID Smoke and Flame (Used existing cameras in tunnel).
  - Approximately 1 nuisance alarm per day per camera.
  - Flashing lights, weather conditions, sunlight at portal.
- VID Flame.
  - No nuisance alarms.
- Optical Flame Detector.
  - Installed without heating elements active - moisture buildup.
  - Buildup of grime and dirt detectors facing traffic – optical faults.
  - Less problems cameras facing with traffic – 3 nuisance alarms/month on average.
- Smoke Detection System.
  - Two systems with sampling in ceiling vents - 2 nuisance alarms.
  - System with sampling line in main exhaust stack became dirty/blocked.

Fire Demonstrations

- November 11, 2007
- 5 fire events.
  - Diesel pan fires in back of stripped-down van.
  - ~1 MW to 2 MW.
  - Burn time ~5 minutes.
  - Rear of vehicle toward detectors.
  - Flame visible through window openings (area 0.44 m²).
- 2 fires near NJ portal.
- 3 fires near center of tunnel.

Fire Demonstrations

Test ID	Fire Location	Dis. From Dets. (m)	Results
Demo 1	Near NJ Portal	61	No detection
Demo 2	Near NJ Portal	30	Only OFD alarmed
Demo 3	Near Center	61	No detection
Demo 4	Near Center	30	Only ASD alarmed
Demo 5	Near Cener	15	OFD and ASD alarmed

Summary Linear Heat Detectors

- Good response to fires – rate of temperature rise.
- Longitudinal airflow can delay response to most fire scenarios.
- Fibre-optic based system indicated location of fire but with longitudinal airflow location could be off by up to 10 m.
- No environmental tests conducted.

Summary Flame Detector

- Initial tests with high sensitivity – reduced to medium sensitivity for later tests.
- Detect open fires within detection range.
- Problems with scenarios with obstructed view.
- Longitudinal airflow could affect response – flames tilted reducing view with obstacles.
- Problems in environmental tests.
  - Dirt and grime led to optical faults on detectors facing traffic.
  - Less problems with devices facing with traffic flow.

Summary VIDs

- All systems able to detect small open fires within detection range (60 m).
- Combined smoke and flame detectors better response for concealed fires and less affected by longitudinal airflow.
- Response of flame based system affected for concealed fires and longitudinal airflow.
- Smoke/flame system installed in Lincoln tunnel had number of nuisance alarms.
- Flame system no nuisance alarms.

Summary Spot Heat Detectors

- Used only in laboratory tunnel tests.
- Responded to fires 1,500 kW or larger.
- Response time could be delayed by longitudinal airflow – reduced temperature at ceiling.
- Not included in environmental tests.

Summary Smoke Detection System

- Able to detect all fires in laboratory tunnel tests except those using a propane burner.
- Longitudinal airflow affected response time.
  - Increased smoke production with some scenarios resulting in earlier response.
  - Response time to small fires increased as smoke diluted by airflow.
- Limited nuisance alarms in Lincoln tunnel.
  - Systems with sampling lines in ceiling vents practical.
  - System in main exhaust blocked in short time.

Acknowledgements

- Authors would like to acknowledge the contributions of following organizations to the project:
  - Port Authority of New York and New Jersey; Ministry of Transportation of Quebec; Ministry of Transportation of Ontario; Ministry of Transportation of British Columbia; City of Edmonton; Carleton University;
  - Siemens Building Technologies; VisionsUSA; AxonX/Johnson Control; Tyco Fire Products; Sureland Industries Fire Safety; Micropack; United Technologies Research Corporation; Det-Tronics; J-power System/Sumitomo Electric; Honeywell;
  - A & G Consultants; PB Foundations;
  - Members of Technical Panel

- Thank you & Questions