OVERVIEW OF WORK PERFORMED BY PIARC C5 WORKING GROUP 6 ON FIRE AND SMOKE CONTROL

Art Bendelius
Parsons Brinckerhoff Quade & Douglas Inc., USA

ABSTRACT

The World Road Association (PIARC) has long included the subject of tunnel safety and ventilation as part of its quadrennial activities. The subject of fire life safety is addressed by its Technical Committee (C-5) and in turn by its Working Group 6 “Fire and Smoke Control in Road Tunnels”. This paper provides a brief overview of the activities of PIARC Working Group 6 principally during the most recent four year PIARC cycle which culminated with the World Road Congress held in Durban, South Africa in October 2003.

1. INTRODUCTION

There are more road tunnels being built to provide access routes across waterways, through mountains or to simply to avoid urban environmental and construction difficulties.

As a result of the significant tunnel fires occurring during the recent years in the European alpine tunnels (Mont Blanc, Taiern and St. Gotthard Tunnels), worldwide interest in road tunnel fire life safety has intensified.

Vehicle fires give rise to particular concern because their consequences can be far greater in a road tunnel than on the open road if no appropriate mitigation measures are taken.

The continuing decrease in road vehicle pollutant emissions is such that the capacity of today's ventilation systems and equipment is usually determined by fire and smoke control considerations. This makes the planning and design decisions regarding the fire emergency extremely critical to the road tunnel construction process.

2. TECHNICAL COMMITTEE

Since it was created in 1957, the PIARC Committee on Road Tunnels (now known as the PIARC Technical Committee on Road Tunnel Operation C-5) has been engaged in the consideration of fire life safety and emergency ventilation (related to fire smoke control) systems and equipment. Information and recommendations in these fields have appeared in the reports C-5 produced for the PIARC World Road Congresses in Rio (1959), Tokyo (1967), Vienna (1979), Sydney (1983), Brussels (1987) and Marrakech (1991).

World Road Association (PIARC)
World Congress Reports on Ventilation

Report to the XVth World Road Congress, Mexico City, Mexico, 1975
Report to the XVIth World Road Congress, Vienna, Austria, 1979
Report to the XVIIth World Road Congress, Sydney, Australia, 1983
Report to the XVIIIth World Road Congress, Brussels, Belgium, 1987
Report to the XIXth World Road Congress, Marrakech, Morocco, 1991, [19.05.B]
Report to the XXth World Road Congress, Montreal, Canada, 1995, [20.05.B]
Report to the XXIst World Road Congress, Kuala Lumpur, Malaysia, 1999, [21.05.B]
Report to the XXIInd World Road Congress, Durban, South Africa, 2003, [22.05.B]

Until the Marrakech Congress the subject of fire and smoke control had been addressed by various working groups within the technical committee, especially those devoted to Operation-Maintenance-Management and to Pollution-Environment-Ventilation.
The working groups aligned with Technical Committee C-5, during the recent PIARC cycle, related to road tunnels were as follows:

Working Group 1  Operation
Working Group 2  Pollution, Ventilation, Environment
Working Group 3  Human Factors of Safety
Working Group 4  Communication Systems and Geometry
Working Group 5  Dangerous Goods
Working Group 6  Fire and Smoke Control

3. WORKING GROUP

In 1992 the Committee on Road Tunnels (C-5) determined that the importance of this subject justified the establishment of a specific working group devoted to fire and smoke control. This new working group, Working Group 6, has, since starting operation, participated in the Congress Reports for the World Road Congresses in Montreal (1995), Kuala Lumpur (1999) and Durban (2003).

This working group has met twice a year since its formation in 1992. The working group meetings have been held in Austria, Finland, France, Germany, Italy, the Netherlands, Norway, Spain, Sweden, Switzerland, the United Kingdom and the United States.

During its initial meetings the working group deemed it necessary to draw up a “state-of-the-art” summary of the primary subjects connected to fire and smoke control in road tunnels. The results of much research, experiences, reflections and even regulatory documents had been published worldwide, but a synthesis was lacking. Early results were published in the report prepared by the Committee on Road Tunnels for the XXth World Road Congress in Montreal in 1995. [1]

The inter-congress report, entitled “Fire and Smoke Control in Road Tunnels” (Figure 1) was published in 1999 in conjunction with the XXIth World Road Congress in Kuala Lumpur [2]. This 1999 report provided the “state-of-the-art” assessment prepared by the working group (a copy of the Table of Contents is at Appendix B). It was intended for all those who are interested in road tunnel planning, design, construction, operation or safety: owners, consultants, operators, researchers, regulators, fire brigades, etc. It provides an overview and recommendations, as well as the background on the way to provide reasonably efficient and cost-effective systems to protect against fire and smoke in road tunnels. It also provides references that are useful to obtain further details.

![Figure 1](image)

**Figure 1**  “Fire and Smoke Control in Road Tunnels” [2]

However, despite the enormous amount of data and information contained in this book experience and research are still needed because the field is quite large and the issues extremely complex: fires in tunnels involve numerous varying and interacting physical phenomena, which have been particularly difficult to investigate.
We do not yet have a complete understanding of the behaviour of a fire in a tunnel, even though our knowledge is quickly improving through numerous research projects. As a consequence further effort will be needed to achieve complete, well-founded and universally accepted guidelines. The PIARC Technical Committee on Road Tunnel Operation (C-5) has continued its efforts towards this goal.

The recent fire incidents in the Mont Blanc, Tauern and St. Gotthard Tunnels during the last few years have led to a situation where safety in transport tunnels, particularly evacuation, rescue and suppression concepts are being scrutinised both in the affected countries as well as worldwide.

3.1. The PIARC Cycle

The PIARC operational cycle is four years in length. Therefore, all committees and working groups have a life of four years. It then follows that all work programs also have a life of four years. Each cycle ends with a World Road Congress which is held every four (4) years. The most recent was held in Durban, South Africa in October 2003. After each World Road Congress PIARC leadership determines which committees and which working groups will be reconstituted for the next cycle based on the PIARC conceptual themes for the upcoming cycle.

3.2. Working Group Meetings

Working Group 6 held eight (8) Meetings in the 2000-2003 cycle in the following locations:

<table>
<thead>
<tr>
<th>City</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lyon</td>
<td>April 2000</td>
</tr>
<tr>
<td>Helsinki</td>
<td>December 2000</td>
</tr>
<tr>
<td>Madrid</td>
<td>April 2001</td>
</tr>
<tr>
<td>Essen</td>
<td>October 2001</td>
</tr>
<tr>
<td>Graz ++</td>
<td>April 2002</td>
</tr>
<tr>
<td>Bad Ragaz ++</td>
<td>September 2002</td>
</tr>
<tr>
<td>Turin ++</td>
<td>January 2003</td>
</tr>
<tr>
<td>Amsterdam ++</td>
<td>April 2003</td>
</tr>
</tbody>
</table>

++ Joint Collaborative Meetings were also held with Working Group 2.

3.3. Working Group Members

The following countries were represented within Working Group 6 Membership during the 1999-2003 cycle:

Members of PIARC Working Group 6 during the 1999-2003 Cycle

- **Australia**
  - Arnold Dix
- **Austria**
  - Rudolf Hörhan
  - Karl Pucher
  - Peter Sturm
- **Finland**
  - Marko Järvinen
- **France**
  - Eric Casale
  - Didier Lacroix
  - Anne Voeltzel
- **Germany**
  - Alfred Haack
  - Dieter Tetzner
  - Werner Foit
- **Italy**
  - Roberto Arditi
  - Giulio Gecchele
- **Japan**
  - Toshinori Mizutani
- **The Netherlands**
  - Hans Huijben
- **Norway**
  - Harald Buvik
- **Spain**
  - Alberto Abella
  - Samuel Estefania
  - Fernando Hacar
- **Sweden**
  - Bernt Freiholtz
- **Switzerland**
  - Ingo Riess
  - Martin Alleman
- **United Kingdom**
  - Norman Rhodes
- **United States of America**
  - Art Bendelius
  - Tony Caserta
3.4. Member Participation

The total Working Group 6 membership during this cycle was 23 members representing 14 countries. The member meeting participation is shown below:

<table>
<thead>
<tr>
<th>Location</th>
<th>Meeting Date</th>
<th>Members Present</th>
<th>Countries Represented</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lyon</td>
<td>April 2000</td>
<td>12</td>
<td>10</td>
</tr>
<tr>
<td>Helsinki</td>
<td>December 2000</td>
<td>14</td>
<td>12</td>
</tr>
<tr>
<td>Madrid</td>
<td>April 2001</td>
<td>18</td>
<td>12</td>
</tr>
<tr>
<td>Essen</td>
<td>October 2001</td>
<td>13</td>
<td>10</td>
</tr>
<tr>
<td>Graz</td>
<td>April 2002</td>
<td>16</td>
<td>13</td>
</tr>
<tr>
<td>Bad Ragaz</td>
<td>September 2002</td>
<td>13</td>
<td>12</td>
</tr>
<tr>
<td>Turin</td>
<td>January 2003</td>
<td>12</td>
<td>10</td>
</tr>
<tr>
<td>Amsterdam</td>
<td>April 2003</td>
<td>14</td>
<td>12</td>
</tr>
</tbody>
</table>

4. APPROVED WORK PLAN

At the beginning of each PIARC cycle each working group must, in conjunction with its respective technical committee develop a work plan to be approved by the respective managing committee.

The approved work plan for WG6 for the 1999-2003 cycle contained the following work tasks:

- Work Plan Task 1. Lessons from Past Disasters
- Work Plan Task 2. Safety Concept for Tunnel Fires
- Work Plan Task 4. (Semi-) Transverse Ventilation
- Work Plan Task 5. Emergency Exits
- Work Plan Task 6. Fire Specific Safety Equipment
- Work Plan Task 7. Fire Response Management

Each of these work plan tasks is briefly described below:

4.1. Work Plan Task 1 - Lessons from Past Disasters

The scope of this work task initially included the creation of a comprehensive data base of tunnel fires which would include tunnel characteristics and response to fire in addition to an in-depth comparative analysis of the recent Mont Blanc and Tauern tunnel fires.

At a later date the data base development was deleted as one of the new thematic networks, Fires in Tunnels (FIT), was planning to develop such a data base. Also as events unfolded with time and another serious road tunnel fire occurred the scope was adjusted to include the fire that occurred in the St. Gotthard Tunnel on 24 October 2001.

The output was intended to be an article in Routes/Roads and a short PIARC report on these fires to be published in 2003. Eventually it was determined that all work of Working Group 6 would be incorporated into a comprehensive inter-congress report to be published in 2004 [3].

4.2. Work Plan Task 2 - Safety Concept for Tunnel Fires

The purpose of this work Plan Task was to develop a set of objectives and design scenarios to address the overall concept of tunnel safety in the event of a tunnel fire. This was intended to include fire development.

The output of this task was intended to be included in a PIARC report to be published in 2003. Eventually it was determined that all work of Working Group 6 would be incorporated into a comprehensive inter-congress report to be published in 2004 [3].
4.3. Work Plan Task 3 - Structures Resistance to Fire

In order to advance all aspects of tunnel structures resistance to fire, the PIARC Technical Committee on Road Tunnels established a collaborative venture with the International Tunneling Association (ITA).

PIARC Working Group 6 on "Fire and Smoke Control" will more specifically determine and present the design fires and resistance objectives, while the ITA through its Working Group 6 on "Repair and Maintenance of Underground Structures" will examine and document the construction methods and material to meet these objectives.

Therefore, the scope of Work Plan Task 3 included continuing work on the collaborative effort with ITA Working Group 6 “Repair and Maintenance of Underground Structures” regarding structures resistance to fire. This work included, as noted above, the development of temperature-time curves for tunnel fires as quantified objectives for both safety and risk of traffic disruption.

The output was to be intended to be a paper published simultaneously in Routes/Roads, Tunneling and Underground Space Technology, and Tunnels in 2001 along with the publication of the joint PIARC - ITA recommendations in 2002-2003.

The Routes/Roads article is currently pending publication. The work will also be presented in ITA’s “Guidelines for Structural Resistance for Road Tunnels to be formally published by ITA in 2004 [4]. This document is currently in draft form (Figure 2). In addition, the work of PIARC Working Group 6 in this area will be incorporated into a comprehensive inter-congress report to be published in 2004 [3].

![Figure 2: “Guidelines for Structural Fire Resistance for Road Tunnels” [4]](image)

4.4. Work Plan Task 4 - (Semi-) Transverse Ventilation

Work Plan Task 4 included discussion of transverse ventilation systems for road tunnels. This scope initially included consideration of both system design and system operation. The output was intended to be a short PIARC report to be published in 2002-2003. Eventually all work of Working Group 6 will be incorporated into a comprehensive inter-congress report to be published in 2004 [3].
4.5. **Work Plan Task 5 - Emergency Exits**
The purpose of this Work Plan Task was to include consideration of the types and characteristics of emergency exits in road tunnels including how to deal with disabled people. Also included was the consideration of the necessary spacing between exits according to people behaviour and tunnel ventilation including escape modeling. This section includes a documented PIARC survey on emergency exits in road tunnels.

The output of this was intended to be included in a short PIARC report to be published in 2002/2003. Eventually it was determined that all work of Working Group 6 would be incorporated into a comprehensive inter-congress report to be published in 2004 [3].

4.6. **Work Plan Task 6 - Fire Specific Safety Equipment**
Work Plan Task 6 included discussion of fire specific safety equipment for road tunnels. This included fire suppression systems such as Sprinklers, water mists and others in addition to automatic fire detection systems. A unique aspect of this section is the documented PIARC survey on fire detection and automatic fire suppression in road tunnels conducted in 2000.

The output of this task was intended to be included in a PIARC “State-of-the-Art report to be published in 2003, however, eventually it was determined that all work of Working Group 6 would be incorporated into a comprehensive inter-congress report to be published in 2004 [3].

4.7. **Work Plan Task 7 - Fire Response Management**
The purpose of this Work Plan Task was to include discussion of the organisation of fire tests for both tunnel commissioning and for staff training (exercises) and of the behaviour expected from users in case of a fire in a road tunnel.

After much discussion within the working group Work Plan Task 9 was combined with Work Plan Task 7 under the title of “Fire Response Management”.

The output of this task was originally intended to be included in a PIARC report to be published in 2003, however eventually it was determined that all work of Working Group 6 would be incorporated into a comprehensive inter-congress report to be published in 2004 [3].

4.8. **Work Plan Task 9 - Emergency Ventilation System Operation-Control**
Work Plan Task 9 was initially to include discussion of methods and systems required to properly operate and control a road tunnel ventilation system during a fire emergency. Work Plan Task 9 was incorporated into a modified Work Plan Task 7.

5. **PIARC PUBLICATIONS**
As noted in conjunction with the Working Group 6 Work Plan Tasks outlined above the following publication plans are underway:

- Routes-Roads Article on Structures Resistance to Fire. {pending publication in 2004}
- Routes/Roads Article on Lessons Learned from Recent Tunnel Fires. {pending publication in 2004}
- Inter-Congress Report titled “Systems and Equipment for Fire and Smoke Control in Road Tunnels” is currently programmed to be published in 2004 [3]. (Figure 3) The proposed Table of Contents is shown at Appendix D. The Table of Contents shows the source (Work Plan Task) of each Section in brackets. This report was prepared in collaboration with PIARC Working Group 2.
The comprehensive PIARC Inter-Congress Report titled “Systems and Equipment for Fire and Smoke Control in Road Tunnels” [3] is composed of eight (8) key technical sections. Each section begins with an introduction subsection which identifies the objectives and if appropriate, addresses earlier work performed by PIARC.

This report should be considered as a supplement to the 1999 report [2] as it supplements the material contained therein it does not replace the earlier publication.

The key technical sections of this document include:

- Section 1 presents an introduction to the effects of smoke propagation at the beginning of a road tunnel fire.
- Section 2 develops some sound safety concepts for the road tunnel. In
- Section 3 addresses the most severe of the recent tunnel fires. These fires are examined and a set of lessons that the industry should learn from these unfortunate incidents are included.
- Section 4 covers aspects of both transverse and longitudinal ventilation along with some of the equipment required for the ventilation system to function properly.
- Section 5 addresses the issue of emergency exits for evacuation, escape and rescue.
- Section 6 contains discussion of the latest technological advancements in fire detection and suppression.
- Section 7 contains the written material that PIARC Working Group 6 provided to ITA as a part of the collaboration agreement noted above related to the criteria to be applied in the development of methods to furnish structural resistance to fire.
- Section 8 includes a discussion of the objectives for smoke control and how these objectives can be achieved by the designers and operators, the factors affecting emergency response teams, the requirement for an Emergency Response Plan, and the importance of maintenance and testing of equipment. The issue of operational responsibilities during a fire based emergency is addressed in
- Section 9 contains a list of suggested subjects to be considered for future research and study.
6. COLLABORATIVE EFFORTS

Collaboration was one of the key themes of the Working Group 6 approved work plan. The purpose was the interact with the organizations from whom the working group could obtain the best input.

The collaboration with ITA and its Working Group 6 had been ongoing for several years before the most recent cycle and therefore had been a most fruitful continuation. We now see, in draft form, the resulting document “Guidelines for Structural Fire Resistance for Road Tunnels”.

Collaboration within the PIARC organisation included fellow working groups such as Working Group 2 “Pollution, Ventilation, Environment”, Working Group 3 “Human Factors of Safety” and Working Group 4 “Communications Systems and Geometry”.

The collaboration with Working Group 2 included deliberations on the following subjects of joint interest:
- Smoke Dampers
- Jet Fans
- Maintenance and Testing
- Ventilation Control

The results of these joint deliberations will appear as jointly written material in the new PIARC publication [3] in Sections 4 & 8 and the Appendices.

The collaborations with Working Groups 3 and 4 related to the work done by Working Group 6 in the area of emergency exits and human behaviour as related to emergency response and evacuation.

7. CONCLUSION

The primary purpose of this paper was to briefly present the results of the activities of the PIARC Working Group 6 “Fire and Smoke Control in Road Tunnels” during the recent cycle. The paper has shown the work performed and the resulting publications produced by this working group. It is clear that the resulting efforts of the working group are a key element in the continuing battle against the impact of fires in road tunnels. This was the result of the over 20 members from 14 countries working together toward a common goal “to improve fire life safety in road tunnels”. The strong participation by all representatives made this cycle’s efforts extremely productive and will result in an excellent documentation of the goals achieved.

The final section, Section 9 as noted above contains a comprehensive list of suggested issues for further study and research. Listed below is a brief abstract of a few of the key items from that list:
- Develop standards for in-situ fire tests for all tunnel ventilation system types to permit comparison of tests.
- Conduct further study of evacuation procedures.
- Develop sample response plans.
- Evaluate the effects on motorists of smoke back-layering.
- Develop clear and reasonable criteria for tenable environment.
- Perform a detailed review of evolving technologies in fire suppression.

8. REFERENCES

[1] PIARC Committee on Road Tunnels (C-5), “Report to the XXth World Road Congress”, Montreal, Canada, September 1995, [20.05.B].
[2] PIARC Committee on Road Tunnels (C-5), Working Group No. 6, “Fire and Smoke Control in Road Tunnels”, 1999, [05.05.B].
[3] PIARC Committee on Road Tunnel Operation (C-5), Working Group No. 6 “Systems and Equipment for Fire and Smoke Control in Road Tunnels”, to be published in 2004, [00.00.B].