"OrGaMIR" – Development of a safety system for reaction to an event with emission of hazardous airborne substances - like a terrorist attack or fire - based on subway climatology"

Andreas Pflitsch, Markus Brüne, Julia Ringeis & Michael Killing-Heinze
Department of Geography, Ruhr-University of Bochum, Germany

ABSTRACT

In case of a fire or the release of an airborne toxin by a terrorist attack in a subway station or tunnel, information on the dispersion of the hazardous substance is important for the rescue operation because it helps to decide which parts of the subway system can be expected to be contaminated. The goal of the ongoing OrGaMIR project is to provide the operating company and rescue forces with this information. In order to predict the dispersion, airflow and thermal conditions inside selected stations in different subway systems are monitored. A number of SF_6 tracer gas experiments were conducted to investigate the spatial and time dependent contamination of the underground air by smoke or toxins. The paper describes the main results of three tracer gas experiments in different subway systems which are characterized by different building structures and ventilation influences.

KEYWORDS: subway climatology, terrorist attack, tunnel ventilation, safety system

INTRODUCTION

Millions of people use public transportation every day. The large number of individuals in the confined space of a subway system, especially during rush hour, makes these systems vulnerable to terrorist attacks.
For several reasons subway systems are exposed to a particular danger of becoming the target of terrorist attacks with C/B weapons. The lifespan of organisms and the half-value period of chemical agents are increased by the lack of sunlight and by the relatively small temperature variations with constantly high temperatures at the same time. Apart from that the paths of diffusion are limited and the possibility of dilution of toxic substances is also extremely limited. Thus a large amount of people can be affected by an attack. Furthermore the escape routes for the passengers are extremely limited and overlap almost completely with the potential paths of diffusion. Especially invisible and odourless toxic gases form a considerable danger for passengers as well as for rescue workers because the paths of expansion can not be observed, contrary to smoke. Thus an appropriate reaction is not possible.
In the OrGaMIR project (Cross-organisational danger defence for the protection of men and critical infrastructures by means of prevention and reaction), a safety system is developed, which will allow the assessment of the prevailing or anticipated contamination of a subway system with hazardous airborne substances [1]. This will enable the stakeholders to take decisions, which may possibly save lives, on a more reliable and informed basis. An overview of the different components is shown in figure 1.

General Goals:
- visualisation of the dispersion of dangerous substances in subway systems and stations
- provision of context-dependent information for decision support
- improvement of teamwork between fire brigade, paramedics and subway operating company

- development of guidelines for the structural design of subway systems in order to minimize the dispersion of dangerous substances

Scientific Goals:
- better understanding of the climatologic conditions inside tunnel systems
- dispersion visualisation in closed architectures
- deduction of recommendations for action from the integration of data of various data sources

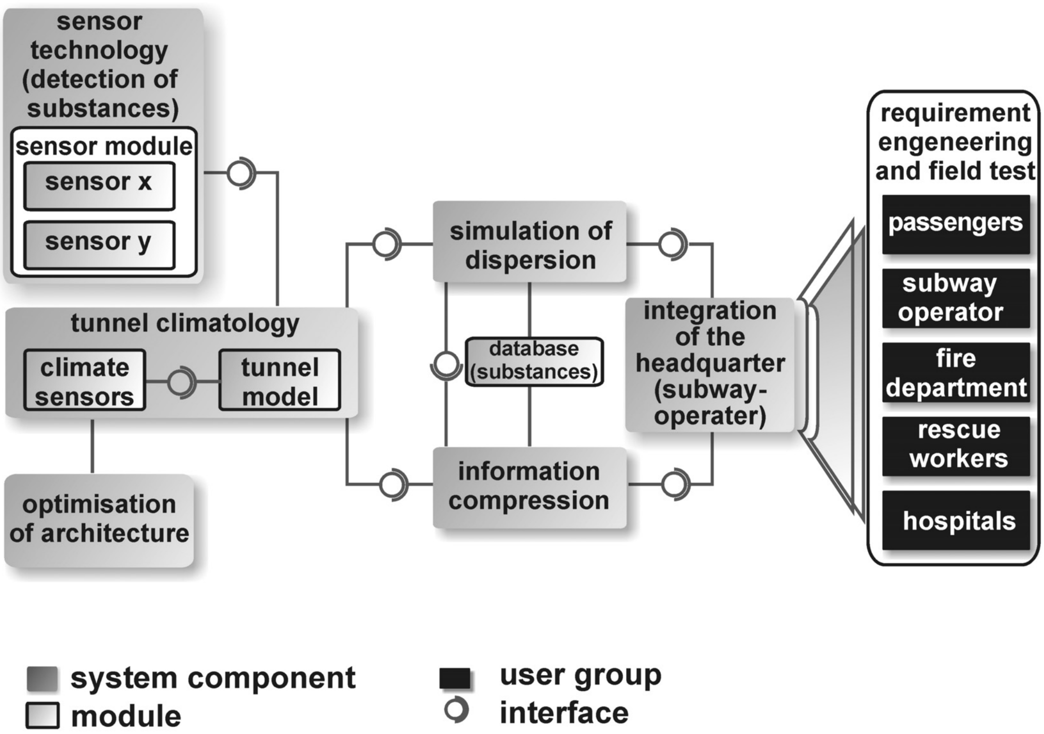

Figure 1: Schematic overview of the different components of the overall project OrGaMIR

The OrGaMIR project (Sponsor: BMBF, lead partner: VDI) has an interdisciplinary character. In order to meet all the requirements, which arise out of the complex field of application, a joint project with a scientific and application oriented consortium was formed (tab. 1).

Table 1: Members of the project consortium of OrGaMIR

Members of the consortium	Focus
University of Paderborn	Information processing & management
Ruhr University, Bochum	Tunnel climatology
Eduard Züblin AG	Subway construction
Institute for Microtechnology GmbH	Sensor technology
Engineering company Lohmeyer GmbH & Co. KG,	Simulation of dispersion
Indanet GmbH	Public transportation control centre management
A fire brigade	End user
Friedrich Schiller University of Jena	Crisis management / psychology
A subway operating company	End user

THE SUB-PROJECT TUNNEL CLIMATOLOGY

In subway systems a great variety of disasters is conceivable. In all of those scenarios the rescue possibilities are extremely limited. Thus first of all it must be clarified what kinds of disasters are possible and what contribution can be made by the findings of subway climatology to certain types of emergency situations.

According to the current state of knowledge the research results of subway climatology will not play a role in connection with derailments or collisions, as long as they do not lead to the development of fire or smoke. If an accident or an engine breakdown leads to a fire which can not be controlled right away it is extremely important to be informed about thermal conditions and airflow in the concerning subway system. This way the expansion of smoke and its effects could be judged properly. But dangerous smoke generation that threatens the lives of staff and passengers can also happen in case of an initially simple cable fire, a fire in an office, shop or computer room that belongs to the subway system or in case of a fire at a station. Furthermore the danger of arson can not be excluded.

Apart from the identification of smoke expansion in case of a fire it is also of particular interest to know about the diffusion of chemical and biological agents that can be distributed during a terrorist attack. For a quick and effective reaction in such an emergency situation, the airflow conditions inside the subway system as well as the determining factors have to be taken into account.

Introduction to subway climatology

In the context of investigations in six different subway systems in Europe and the USA the existence of a steady base- and background-airflow which is independent from the train service and active ventilation could be demonstrated unexceptionally and clearly [2]. The demonstration that the air flow is not a matter of a simple, temporally constant air movement but a highly complex flow system which shows numerous spatial and temporal variations was equally clear [3].

The development of the thermal situation, meaning the temperature difference between the outside atmosphere and the air inside the tunnels and stations, and the weather conditions of the outside atmosphere (stability, wind field) were identified as most important influencing factors for the specific characteristics of the background-air flow [4 & 5].

The amount and speed of the effect of outer weather conditions on a subway system is also influenced by the type of passive ventilation. In open systems like in New York City the outside weather conditions can have significantly more influence on deeper parts of the underground as in those subway systems that have only few openings to the surface such as in Dortmund [3 & 6]. Thus air masses that infiltrate the system from the outside through gratings which are distributed over the whole subway system in New York City can rapidly cover the whole tunnel system. In Dortmund on the other hand there is an inner sector with rather constant conditions and a border area with great variations in air flow conditions. In conclusion it can be said that huge thermal differences lead to strong compensating currents, while the flow system almost comes to a standstill when there are no temperature differences. Another effective stimulation is the wind pressure onto the tunnel entrances [7].

Most important for the implementation of the available results is the proof that the background flow is not confined to the periods when the train service is shut down but it is also clearly existent during the times when the trains are running. Hence it is a constantly existing phenomenon. However during operation time this background flow is being more or less modified by the train service. The intensity of the superimposition depends on the cycle of trains as well as on the architecture of tunnels and stations. This fact is particularly relevant for a judgement of an anticipated spread of toxic substances in the course of a terrorist attack because the background flow consequently also influences the spread while the trains are running [8].

Finally the project OrGaMIR clarifies which concrete practical relevance the so far verified climatologic phenomena in subway systems have for the prevention of disasters like fires and terrorist attacks and for the resource planning in such emergency situations and which of the already advised measures should be taken [9 & 10].

Fires vs. terror attacks

Both kinds of disasters – fires and terrorist attacks – are fundamentally different in many respects. The only similarity is the harmful and deathly outcome of the smoke and gas clouds which spread inside the subway system. There are numerous differences that are listed below as a comparison of both emergency situations [11].

Table 2: Comparison of the emergency situations fire and terrorist attack with C/B-weapons in a subway system - modified from SANCHEZ et al. 2000 [12].

Fire (technical fault, accident)	Terrorist attack
The fire is restricted to a more or less limited area.	The release of C/B weapons is possible in the whole system.
A fire is noticed immediately.	An attack can possibly happen unnoticed.
Detector technology exists and is fully developed, possibly cameras are sufficient.	Detector technology is still being developed, cameras only record collapsing passengers.
Fire and smoke can be localised clearly.	The localisation of the source can be difficult or impossible.
The source of heat and smoke is static.	A release inside a train means that the source is mobile over a longer time period.
The smoke is visible to the victims/rescue service.	Many agents are invisible.
The smoke and heat development of a fire can be estimated because relevant investigations exist.	Even if the source can be localised the expansion of toxic substances can happen very dynamical depending on kind and place of the release (explosion, pump mechanism) and can not be reconstructed when discovered later on.
Due to the generation of heat the expansion of smoke can be estimated more easily close to the source.	The expansion of toxic substances exclusively depends on the present flow situation in the subway system.

This comparison makes clear that the patters of release as well as the patterns of spread of smoke and gas clouds which are caused by accidents or technical faults leading to fires or by terrorist attacks on the other hand are significantly different. The same applies to the proof that both disaster scenarios are existent; for this reason both subject areas are treated separately in the project.

In this article the area of terrorist attacks and particularly the spread of toxic gases are highlighted.

Spread and effect of chemical and biological agents in subway systems

For several reasons subway systems are exposed to a particular danger of becoming the target of terrorist attacks with C/B weapons. The lifespan of organisms and the half-value period of chemical agents are increased by the lack of sunlight and by the relatively low temperature variations with constantly high temperatures at the same time. Apart from that the paths of expansion are limited and the possibility of dilution of toxic substances is also extremely limited. Thus a large amount of people can be affected in close proximity by an attack. This especially applies to the rush hour in the morning and in the evening when many people are in the subway system and an assassin would hardly be noticed.

The possible spread of C/B weapons is versatile and almost unpredictable, as examples from Tokyo show [13]. In the attack from April 20th 1995 12 people died from the evaporation of sarin within five days. In the second attack cyanide was spread with a fire [12]. Apart from that the release of toxic agents is possible via remote-controlled evaporators, explosions or via utilisation of the piston effect of running trains to release a poison on the tracks. The release of C/B weapons inside a flue would have direct effects inside as well as outside the subway.

Contrary to the subway company's operation schedule for fires the use of active ventilation – if existent – should be avoided in case of an attack with C/B weapons. Calculations of the Argonne National Laboratory already showed ten years ago that the ventilators that were installed for decontamination should only be used if substances are lowly concentrated and hardly poisonous. In case of a terrorist attack e.g. with nerve gas or biological substances the use of ventilation would increase the number of victims *outside* the subway system dramatically [8 & 12]. It must be taken into consideration that clouds of toxic gases can travel seven to ten kilometres at the surface and thereby would contaminate surrounding buildings, especially via their gratings [14].

Assuming that the ventilation of a subway system – if existent – is being rightly deactivated in case of such a disaster, the character of the natural subway climate becomes highly important for the way of spreading of toxic substances. Taking into account that between the release of a substance and the detection of this disaster, including the stop of the train service, a certain time goes by, there will first be a spreading of the dangerous substances due to the running trains. This is either supported or constrained by the respective ground flow.

Thereby it must be differentiated in which places the poison is released because the further spreading strongly depends on that. The different points of emission for C/B weapons inside a subway system would be: inside a tunnel, a subway station, a train, a grating or in the area of support and working facilities.

The above mentioned possible places of emission were analysed in regard to their hazard potential already in 2001 [8], considering their specific climate conditions. With the help of different examples the strong influence of the thermal conditions and the effect of the air flow system on the spreading of chemical and biological substances inside subway systems and in close-by surface areas could be clearly demonstrated. Especially the fact that the spread of such toxins solely depends on the flow conditions, meaning on the exchange situation inside the stations and tunnels and between the subway system and the outside atmosphere, demonstrated already then explicitly the necessity to extend this area of research in the future to be able to avoid disasters or to effectively combat them. The project OrGaMIR is based on those realisations which allowed the extraction of the following tasks/questions for the subproject tunnel climatology.

Scientific and technical goals of the sub-project

Aim of the project tunnel climatology within the OrGaMIR project is to provide reliable information on the current and upcoming air flow and dispersion conditions inside a subway system (tunnels and stations). Comprehensive knowledge of this is indispensible for a simultaneous analysis of the dispersion of airborne toxins (gases, dust, fog) in case of an incident and a basic requirement for all decisions and activities regarding the rescue operation.

The biggest obstacle in a rescue operation in a subway environment is the restricted access to the site of the incident. Today there is no information available on the parts of the subway system that are affected by an incident, such as neighbouring tunnels and stations, and which parts are not contaminated and allow access for the rescue teams and can be used as escape routes. In order to improve this situation and to reduce the number of persons affected, rescue teams and operating company need exact and reliable information on the current and imminent situation. Information distribution and coordination of organisational and logistic procedures is a task which must be met by a cross-organisational emergency task force which has to be set up under the lead of the fire department.

The project tunnel climatology supplies the data base for the overall project. The knowledge gained in previous research campaigns on the system-specific air flow regime, which develops in every subway system independent of the train traffic, is to be applied in the overall project. This includes:

- The setup of a measurement system for the registration of the current air flow conditions. An example of a current setup can be seen in figure 2. This configuration is build up for the basic research and does not show a later operational system. The air flow is mostly measured by ultrasonic anemometers [15].
- The development of a model for the short-term prognosis of the stability of the prevailing air flow conditions and for the identification of danger zones.

In addition to this the sub-project will deliver:

- Information on the required number and sensible positioning of the sensors for the detection of CBNRE-substances.
- Information concerning a structural design of subway systems which help to minimize the dispersion of dangerous substances.

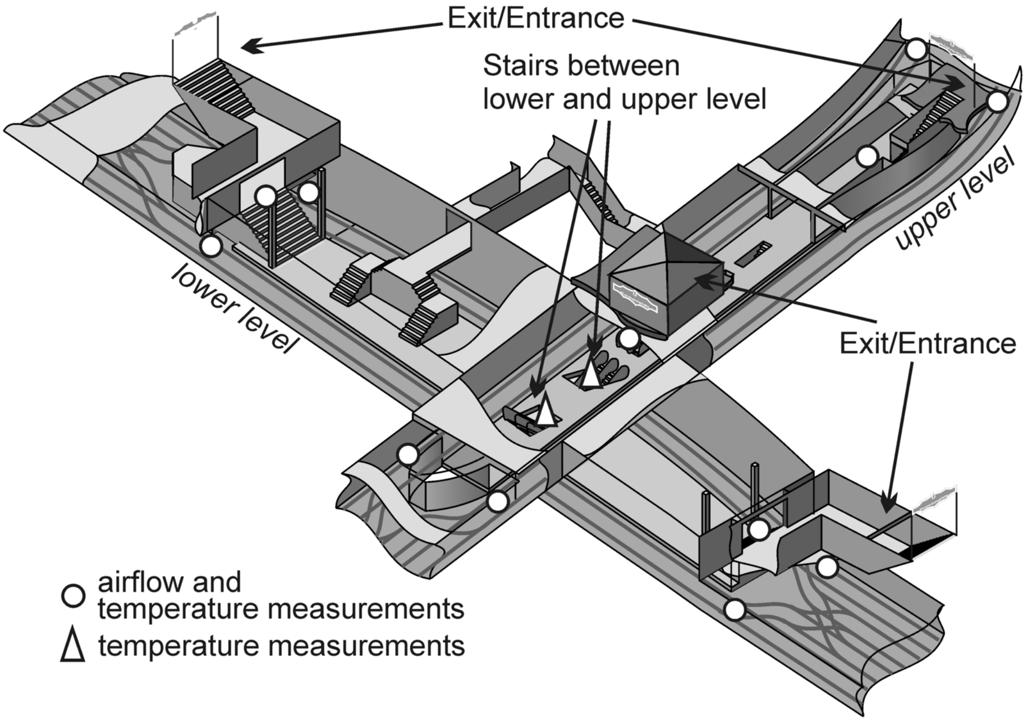

Figure 2: Location of air flow and temperature sensors inside one of the subway stations of research investigation

The so far existing realisations - which will be completed by further investigations - about the formation of a natural background current and the exchange conditions inside a subway system will be included in a planned security concept which allows new strategies for the preventive disaster control as well as for the possible case of emergency. Trusted information about the climatic and meteorological general conditions which prevail in the context of an emergency and the conditions in the systems are used to develop a computer-controlled, system specific scheme for diagnosis and prediction which diagnoses the thermal situation as well as the flow conditions inside the affected system within one minute in case of emergency. Based on a measuring campaign that determined the characteristic influencing factors, conditions and variability of the climate system in the subway system the relevant general conditions have to be available completely. Apart from that they contain favourable locations of emergency exits and descriptions of the timeframe that is available for escape and rescue. Hereby the rescue of victims from the place of the accident and the evacuation of the population from the most endangered areas of the tunnel system and the surrounding areas at the surface are possible. The fast (self) rescue of the victims of the fire or terrorist attack onto a subway system by the use of a present time frame and the evacuation of the indirectly threatened population inside the concerned subway system are the two final aims of the project.

RESULTS

The ongoing project did already deliver many very interesting results, which can not all be presented here. One of the most important results should be made public as soon as possible, concerning the outcome of several tracer gas experiments. Additionally to the stationary climatologic measurements a number of SF_6 tracer gas experiments were conducted to investigate:

- the current air flow and thermal regime under the conditions of different atmospheric stabilities in and outside the underground and
- the spatial and time dependent contamination of the underground air by smoke or toxins.

So far the results of emissions of tracer gases in two different subway systems with different structures and ventilation influences are available. The spreading of gas inside a station as well as inside the tunnel system between the different stations was analysed.
As an example the results of two gas emissions in the above mentioned station are listed. The station consists of two levels where the trains cross each other. The levels are connected to each other via stairs and escalators. Both levels are directly connected to the surface.
At Dec. 2nd 2008 and June 3rd 2009 the tracer gas SF_6 was released at the lower level of the station over a time period of two minutes. The gas was released at night while the train service was shut down to investigate a stagnant system in which only the natural background flow is responsible for the diffusion of gas. Due to the fact that SF_6 is six times heavier than air it was mixed with air to avoid an immediate descent. The expansion of the mixture of SF_6 and air was monitored with the help of air samples which were taken every minute with an injection and later analysed in a lab at the department of Geography at the university of Duisburg-Essen (Prof. Kuttler). Figure 3 shows the spot of emission on the lower level and the locations where the samples were taken in the area of the four exits, the eight tunnel portals and the two staircases between the two passenger platforms.

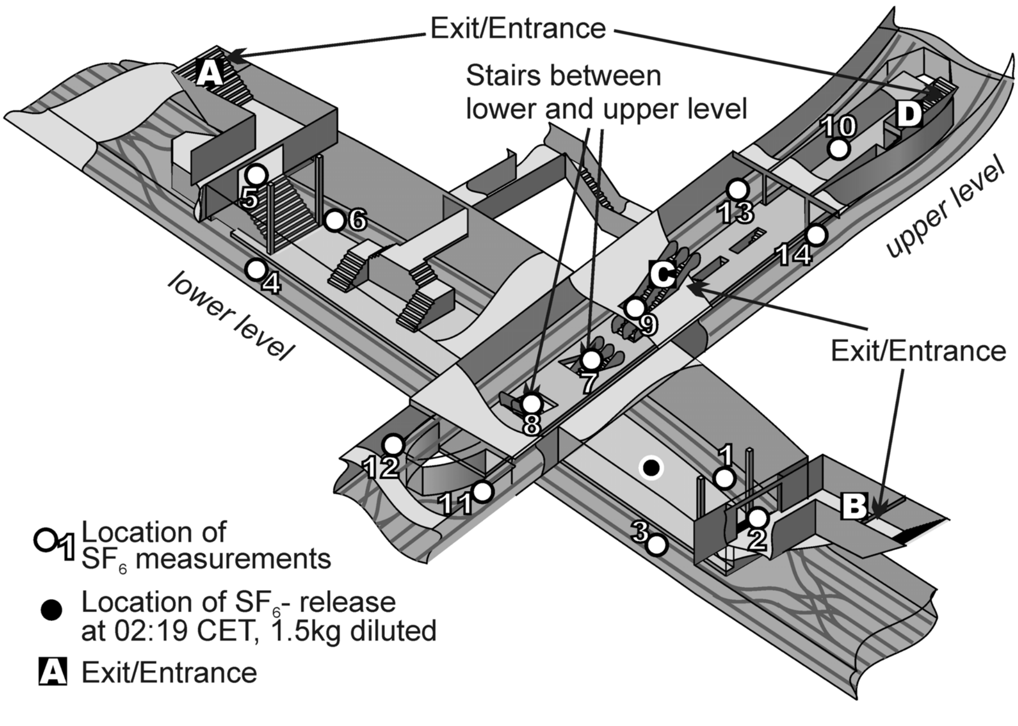

Figure 3: Location of release and measurements of the tracer gas in the subway station of investigation, Dec. 2nd 2008 & June 3rd 2009.

The samples were taken at the different measuring spots in different heights as follows:

Locations 1, 3, 4 & 6:	Directly at the tracks and 1.5 m above the passenger platform
Locations 2 & 5:	Directly at the floor and 1.5 m above the staircase
Locations 7, 8, 9 & 10:	Directly at the floor and straight under the ceiling
Locations 11, 12, 13 & 14:	1.5 m above the passenger platform

In order to measure the time for self rescue in detail the samples were taken over a period of 15 minutes. The results are shown in figures 4a to 4d.

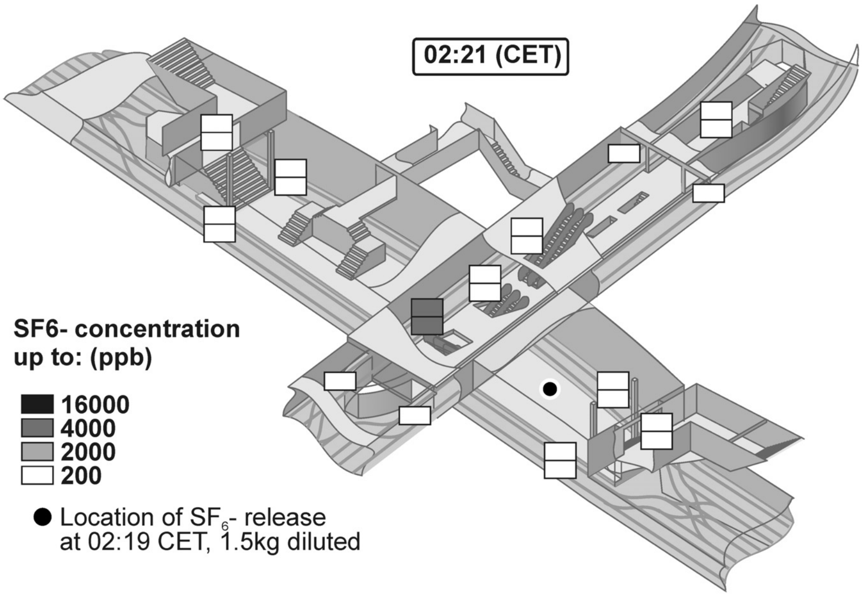

Figure 4a: SF_6-concentration in the subway station of investigation 2 minutes after release of the tracer gas, Dec. 2nd 2008

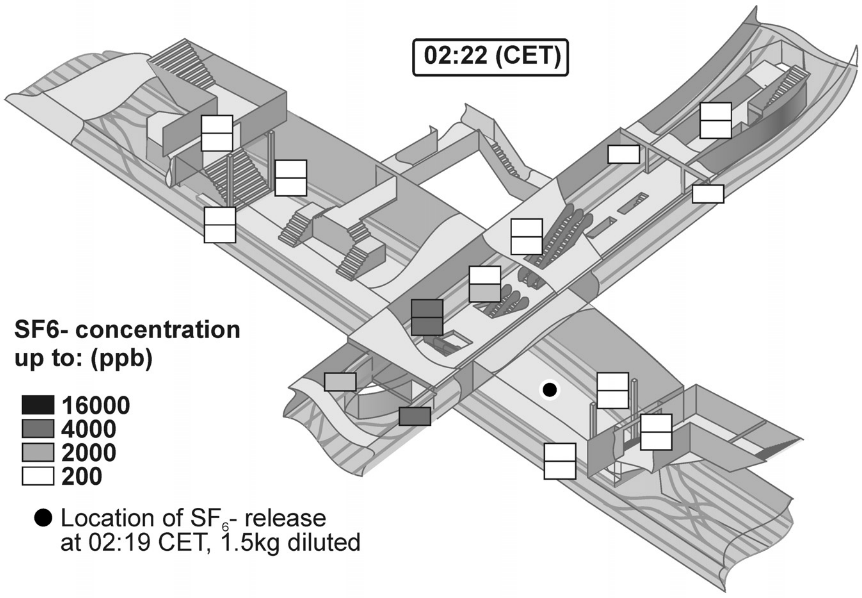

Figure 4b: SF_6-concentration in the subway station of investigation 3 minutes after release of the tracer gas, Dec. 2nd 2008

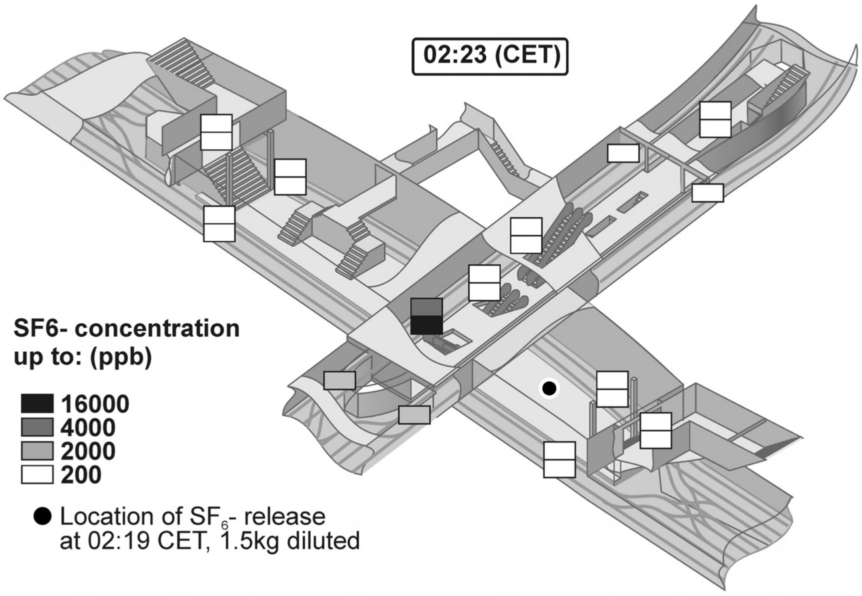

Figure 4c: SF_6-concentration in the subway station of investigation 4 minutes after release of the tracer gas, Dec. 2nd 2008

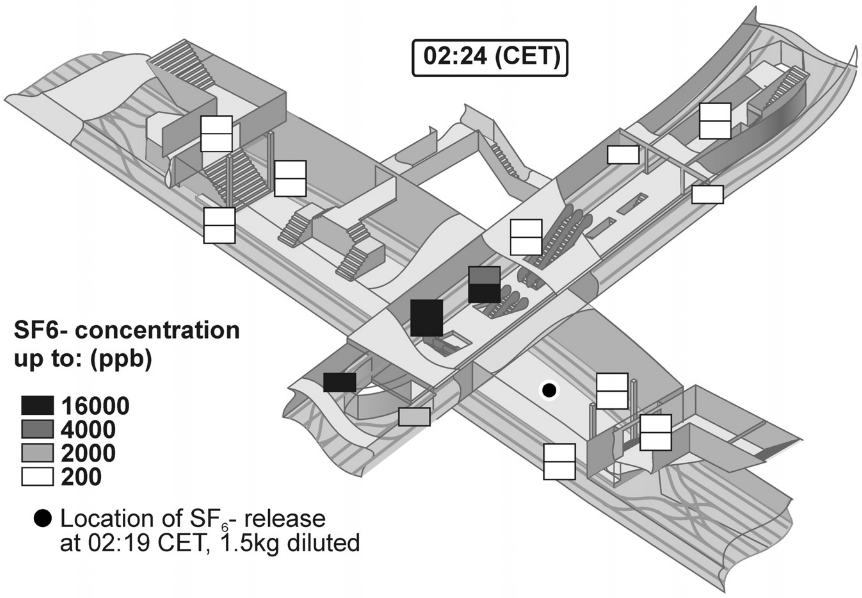

Figure 4d: SF_6-concentration in the subway station of investigation 5 minutes after release of the tracer gas, Dec. 2nd 2008

It becomes obvious that the spreading of the tracer gas from the point of emission happens directly above the two staircases into the direction of the upper level while the two exits on the lower level are not reached. In the upper level the gas can not spread completely but is conducted directly above exit C, the two tunnel portals close to the measurement points 11 and 12 and for a short period with a low concentration through exit D. This situation persists over the whole measuring period. Looking at the prevailing flow situation at the measuring time inside the station it becomes clear that the spreading situation could have been predicted clearly with the help of flow measurements (fig 5).
The second measuring campaign at the same station at June 3rd 2009 showed a similar result. The bigger part of the contaminated gas flew through the two staircases into the upper level and was conducted through the middle exit and the tunnel portal. In contrast to the measurement in December in June also a part of the lower level - around the area of emission, until into the tunnel – was

contaminated. This can be explained by a weak general flow with changing directions at the lower level.

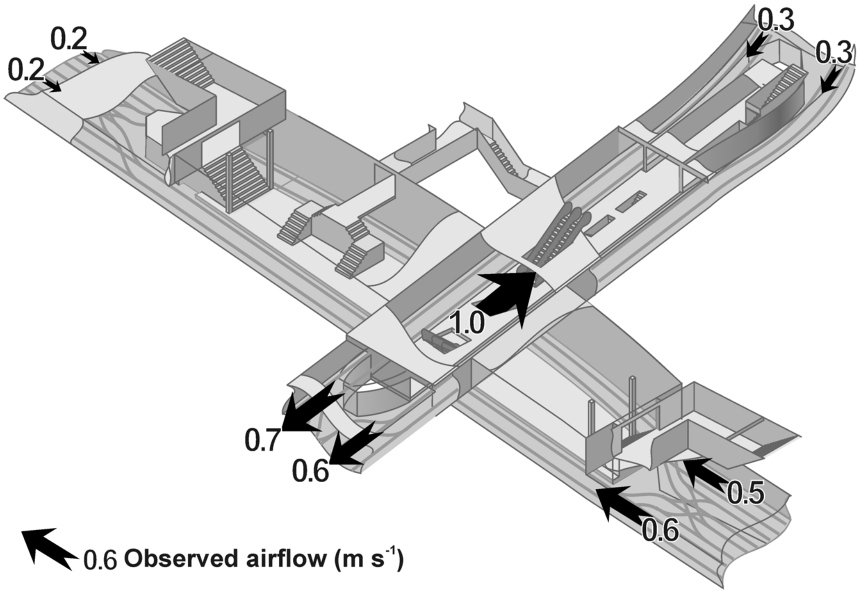

Figure 5: Air flow regime at the subway station of investigation, Dec. 2nd 2008, 2:20 to 2:35 CET

Similar observations were made during another emission of gas in another subway system. The gas – heavier than air – flew through the staircases towards the surface. The all over results about the danger areas and the escape routes for the most common air flow situation in the subway station of investigation is shown in figure 6.

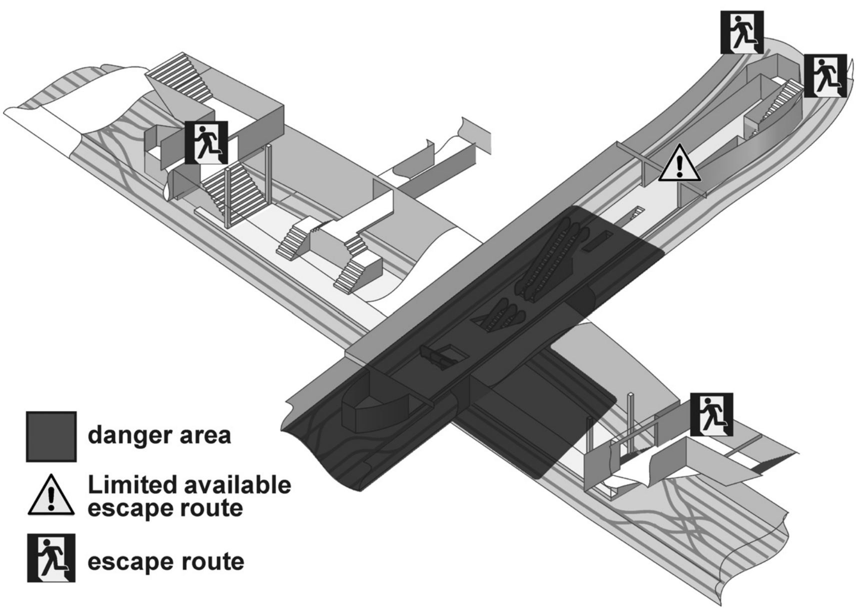

Figure 6: Results about the danger areas and the escape routes for the most common air flow situation in the subway station of investigation.

CONCLUSION

Conclusively all the tracer experiments have verified the previous findings of the flow measurements. Staircases, especially between different levels of a station, often act as "flues". For entrances and exits of the station the situation is less clear. Many of them act as flues; but there are also entrances through which – at least temporarily – cold air flows into the station.
What do these results mean for the evacuation of a station? The designated emergency exits in many subway stations which often lead directly to the surface (fig. 7) would mean the death of the passengers in case of a fire or an attack with toxic gas.

Figure 7: Typical sign for an escape route in subway station showing upwards (Tokyo, 2009).

A good example for this are the numerous victims in the subway of Daegu (South Korea [16]). Here many passengers died in the floors above the actual fire source due to smoke that flowed upward. Although this case was about a fire and flowing hot gases, the previous tracer experiments have shown that even gases that are heavier than air can have enough buoyancy due to the natural flow conditions to flow rapidly upward to higher levels of the station.
The results show very clearly that some of the signed escape and rescue ways are very often the worst solution for the escaping passengers. Especially long stairway or escalators leading in higher levels or to the surface are favoured structures for developing a strong chimney effect, which leads the gas as well as the passengers to the surface. Thus a rethinking is necessary when it comes to the designation of emergency exits. A flexible escape route that is adjusted to the respective spreading situation is absolutely necessary. The new research field of subway climatology and the project OrGaMIR will contribute to this.

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