RIVM report 630110002 / 2006

Risk assessment for populations during inhalation exposure as a result of catastrophes

H.J.Th. Bloemen and F.R. Cassee

Contact:
H.J.Th. Bloemen
RIVM
Laboratory of Environmental Monitoring
e-mail: Henk.Bloemen@rivm.nl

This investigation has been performed within the strategic research program of the RIVM.

Rijksinstituut voor Volksgezondheid en Milieu (RIVM), Postbus 1, 3720 BA Bilthoven, telefoon: 030 - 274 91 11; fax: 030 - 274 29 71

Abstract

Risk assessment for populations during inhalation exposure as a result of catastrophes

In the first phase of the RISPIEC project on '*risk assessment for populations during inhalation exposure as a result of catastrophes by integrated monitoring and modelling*'-inventories are compiled including tools required for supporting the authorities in the case of calamities and available directly or after brief modifications. Furthermore, an initial list of substances has been compiled which are considered as having priority for inclusion in future developments of the anticipated integrated assessment instrumentation and procedures. The priority-setting is based on the known health effects and the estimated environmental risks related to the intensity of use and transport.

Key words: Emergency response support, inhalation, exposure, risk assessment

Rapport in het kort

Risicoschatting voor populaties na inhalatoire blootstelling bij rampen

Er is een inventarisatie gemaakt van beschikbare RIVM-onderzoeksmiddelen om rampen waarbij gevaarlijke stoffen vrijkomen te monitoren en te bestrijden. De middelen bestaan uit meetapparatuur en rekenmodules. In de inventarisatie zijn ook onderzoeksmiddelen ondergebracht die alleen een kleine modificatie nodig hebben om ingezet te worden.

Deze inventarisatie is gemaakt in het kader van het project RISPIEC (*Risk Assessment for Populations during inhalation Exposure as a result of Catastrophes integrated monitoring and modelling*). De doelstelling van dit project is het gereedmaken van de onderzoeksmiddelen die door het RIVM worden ingezet bij het beoordelen van de gezondheidsrisico's van rampen of calamiteiten.

Binnen het RISPIEC project is ook een lijst beschikbaar van risicovolle stoffen. De selectie is gebaseerd op gezondheidseffecten en het milieurisico (stoffen die intensief gebruikt en getransporteerd worden).

Trefwoorden: risicoschatting, inhalatoire blootstelling, rampen

Preface

A few recent examples of major catastrophes in the Netherlands signalled a need for a systematic approach to assessing the individual exposure to chemicals emitted shortly after the onset of an event. The initial activities undertaken to address this need are described in this report.

The authors would like to thank the following people for their valuable contributions to this project: Andre van Vliet, Arnold van de Beek, Bert Zomer, Christiaan Delmaar, Elbert Hogendoorn, Erik Lebret, Hans van Jaarsveld, Henk Heusinkveld, Jacqueline van Engelen, Jan Kliest, Jan Linders, Jan van Eijkeren, Linda Stolker, Marc Ruijten, Marcel Broekman, Marcel Mennen, Mark van Bruggen, Paul Fischer, Petra Krystek, Ramon Ramlal, Renata de Winter, Rob Ritsema, Sander van Dijk, Wilbert Slooff

Bilthoven, 1 January 2006

Henk Bloemen

Contents

SAMENVATTING 6

1. INTRODUCTION 7

2. THE RRA CONCEPT 9

3. OBJECTIVES AND APPROACH 10

4. RECOMMENDATIONS FROM THE NETWORK 12

5. SELECTION OF SUBSTANCES AND INTERVALS 14

6. EVALUATION OF DISPERSION AND EXPOSURE MODELS 16

6.1 DISPERSION MODELS 16
6.2 POPULATION EXPOSURE MODELS 17

7. DISCUSSION AND CONCLUSION 21

ANNEX 1: RISPIEC POSTER 23

Samenvatting

RISPIEC: *Risk assessment for Populations during Inhalation Exposure as a result of Catastrophes integrated monitoring and modelling*. Het doel van dit project was het verkrijgen van een set op elkaar afgestemde onderzoeksmiddelen (meetmethoden, modellen) en procedures om het risico voor een populatie die mogelijk is blootgesteld aan chemische stoffen die vrij komen bij rampen zo goed mogelijk te kunnen bepalen.
Deze middelen omvatten methoden om concentraties te bepalen in de lucht als ook modellen waarmee de concentratie op een bepaalde plek kan worden berekend. Met de hiermee verkregen informatie kan vervolgens een beschrijving worden gemaakt van de blootstelling en interne dosis gedurende een bepaalde periode. Dit gebeurt op basis van de tijd-activiteitenpatronen van de betreffende populatie, depositiemechanismen (samen AirDose) en procedures waarin deze middelen worden toegepast (samen STAQA - Short Term Air Quality Assessment). Om dit doel te bereiken werden de volgende activiteiten ondernomen:

1. verbetering of ontwikkeling van bemonstering en analytische meettechnieken
2. selectie van stoffen en tijdsintervallen
3. harmonisatie van dispersie en blootstellingmodellen
4. ontwikkeling van AirDose
5. integratie van de onderzoeksmiddelen en procedures

Dit rapport geeft een overzicht van het in dit project behaalde resultaat tot aan het moment dat de financiering werd stopgezet.

1. Introduction

Recent severe events in the Netherlands and abroad and their eminent threats set off a rapidly growing interest in health impacts caused by exposure to harmful substances emitted during these catastrophes (large-scale disasters or accidents, terrorist attacks). This new type of health risk assessment is clearly distinct from the research into health risks related to long-term, low-concentration exposure, a field of research and regulations in the environmental scientific and regulatory community's focus for decades. High-dose exposure has occurred mainly in industrial settings; it is regulated by a series of directives focused on the protection of workers dealing with substances expected to be released during incidents or accidents. Research in both fields, environmental toxicology and industrial hygiene, has generated substantial information for a large number of substances of which the health effects are known and for which maximum levels (dealing with short-term as well as long-term exposure) are set.

Much less is known about the effects of these substances at higher exposure doses to the general population or of substances not yet considered potentially harmful to this population. This lack of information does not only relate to the health effects directly after an event but includes the delayed effects too. Consequently, practical action values can only be based on educated assumptions using all data available.

Risk evaluation related to catastrophes is characterized by the inevitability to provide a first risk estimate within a relatively short time (hours to days) after the initiation of the event. It is importance to have quick insight into (potential) risks for immediate and adequate measures to be taken by the responsible authorities. The required information includes exposure and risk assessments for the population living nearby and for relief workers, including the side effects of the actions. This type of assessment is known as Rapid Risk Assessment (RRA), which is currently developed in a large number of countries, either as newly formed authorities dealing with terrorist threats and attacks or as organizations responsible for the well-being of threatened populations.

In the Netherlands the Environment Emergency Response Organization (MOD), part of the Environmental Safety Division (MEV) of the National Institute for Public Health and the Environment (RIVM) has the responsibility of performing an early exposure and risk assessment and has to collect data necessary for a follow-up investigation where the seriousness or magnitude of the catastrophe calls for it. When the MOD responses to an emergency call, a broad-based network at the RIVM comes into action to rapidly collect data for the early-exposure and risk assessment. This includes a field investigation team, back-office for dispersion model calculations and information on the chemical process. Regional networks or the national network also respond (this includes the national coordination network, fire fighters, relief workers, hospitals and others).

Whenever the risk assessment needs to be extended in scale and over time, the RIVM's Centre for Health Impact Assessment (CGOR) coordinates a more extensive health survey. Exposure assessment data gathered in the first phase by the MOD is essential to allow the distinction between the population exposed to the dramatic aspects of the event and the sub-population also exposed to harmful substances.

MOD sets specific requirements for the data collection in the initial phase, such as information to support the selection of biomarkers and an after-the-fact proxy. This proxy is to validate the exposure assessment using dispersion data and the coordinates of the space in which individuals find themselves at the time of the calamity.

Figure 1: Bijlmer airplane crash disaster.

A number of technologies and approaches are already in place for both the initial and the second phase of the rapid risk assessment. These are frequently used for a number of relatively small scale calamities and in a limited number of cases for calamities, in which a large number of casualties and injured people are involved. Although the responses in the past often satisfy the expectations for exposure and risk information, the need to further the preparedness of the organization (MOD) is articulated frequently.

Initially, the concept of RRA used in this project was based on the expertise of and experience with the recent emergency responses to calamities in the Netherlands and a small number of large disasters abroad. All of these were classified as unintended mishaps. Since the dramatic events of 9-11 numerous governmental institutions have taken up the task of improving the preparedness They have launched various programmes for designing and developing means to deal with a variety of aspects. These programmes are currently operational in the USA (where initiatives come from the Department of Home Security and many other related research programmes) and Europe (where various EU initiatives run parallel to the 6^{th} Framework Programme). Although these programmes are mainly focused on terrorist attacks, the aftermath of both types of disasters, unintended or mal-intended and threatening human health, show important similarities. The developments emerging from the programs are expected to be of relevance to this project. Hence, during the first year of the project the scope was widened to incorporate techniques, approaches and concepts developed elsewhere. In early 2004, however, it was decided to cancel this project for reasons discussed further on.

The report will present the initial results of the project. Since the project was cancelled, the results of the project will not show the coherence that might be expected. Nevertheless, as the need for techniques and tools for RRA will not vanish, the information presented might prove to be useful.

2. The RRA concept

Rapid Risk Assessment is considered the set of techniques and data, skills and expertise that produces a health risk estimate in the shortest possible time. The quality of this estimate will improve during the course of the event it is dealing with until the risk is considered negligible or measures can be defined that can control the risk at hand.

This implies the application of initially RRA tools to comply with the limited accuracy requirements but that are easy and fast to apply. These tools will then be replaced during the course of the event by finer-tuned, and consequently more time-consuming RRA tools, whenever the need for more accurate ones becomes manifest.

3. Objectives and approach

The set of tools to be developed in the framework of this project would be used: (i) to assess health risks for a (sub-) population exposed to substances emitted during a catastrophic event and (ii) to distinguish between people exposed to these substances and those exposed to solely the dramatic effects of the event. These tools are comprised of measurement instrumentation and methods, computer models, methodologies, approaches and procedures geared for use in the succeeding stadiums of the event and characterized by increasing accuracy.

As previously mentioned, it is expected that before developments in other foreign institutes progress rapidly. It is expected that by consulting the existing network opportunities will arise to incorporate the newly developed tools allowing collaboration with these groups.

Figure 2: Fireworks disaster in Enschede.

Various routes of exposure are possible. For feasibility reasons the inhalation route is the only one considered here. In the recent past the majority of cases dealt with the inhalation route (nearly) exclusively. In the short MOD history the food chain was occasionally indirectly relevant (e.g. dioxin in cow milk). In the experiences with the inhalation route, it is anticipated that directions will be given later on to set up tools for other routes as well.

The focus in the first years was on the modification of existing methodologies and models for both dispersion and exposure assessment based on a list of compounds expected to be involved in calamities. This list assumed their occurrence in the Netherlands, the amount of material in storage and transport, their health risks upon human exposure and the availability of toxicological information. Compounds for which insufficient data were available were left out in this phase, not withstanding the relevance of their potential toxicity. Methodology for sampling and analysis based on proven technology and their possibility for implementation in the analytical infrastructure of the RIVM and possibly in other research organizations in the Netherlands. Models are already used at the institute or in a collaborative grouping to which the RIVM is a party.

The project consisted of the following activities:

1. Organizing a workshop at the RIVM with experts in the different fields of measurement and modeling, as well as those active in the field of RRA (MOD and CGOR). The purpose was to further substantiate the objectives of the project and to complete and discuss the inventory of tools useful for the project. A further aim was to consult experts in the emerging network

2. Selecting the chemical substances to be included in the modification and development of tools based on the above-mentioned criteria.
3. Summarizing the available measurement methods and defining the applicability and the need for further modification and development.
4. Summarizing the available dispersion and exposure models, and defining the applicability and the need for further modification and development.
5. Incorporating the new techniques in the day-to-day operation of the emergency response organization by implementing methods, stipulating procedures and training operators.

The next section presents the first results of the various activities. As mentioned above, not all the steps have been completed; furthermore, activities 3 and 5 will not be included at all in this report.

Figure 3: Monitoring a benzene spill in Rotterdam.

4. Recommendations from the network

Experts from the institute and from other organizations in the Netherlands and abroad were consulted to optimize the information and insights for launching the project. Consultations with the experts led to the following recommendations:

- Evaluate the HEES database and an ATSDR project focusing on the emissions of hydrochloric acid, ammonia, and chlorine during a fire.
- Consider the use of GASMAL van DCMR of CHEMIO (US model is AEGL).
- Make use of the Department of Energy, Meteorological Coordinating Council database of 80-100 substances.
- Consult the results of the EU project (TEAHEAS) focusing on the regional deposition of gases and acute effects and AEGL for durations of 10 minutes to 8 hours.
- Consider the use of Acutex for the evaluation of acute effects in sensitive groups.
- Explore the possibilities of OPS-KT (short-term) for coupling GIS with concentration estimates to obtain concentrations for each relevant coordinate as input for exposure modelling.
- Modify some features of AIRPEX for short exposure periods and compile time activity patterns to be used in AIRPEX for calamities.
- Make the dosimetry model for particles available for gaseous substances; besides AIRPEX, ConsExpos also to be considered for indoor/outdoor rations.
- Improve measurements: preferable to use field measurements, if not possible use a representive sampling method. The fire brigade project (IMD) might prove useful.
- Improve information on meteorological parameters. A local meteo-station might be required.
- Contact Professor Pat Sandra, an analytical chemist and international authority on chromatographic methods (R.I.C. Research Institute for Chromatography, Kortrijk, Belgium). He and his groups focus on emissions from fires. Polar compounds seem to be relevant substances.
- Consult one of the Frauenhofer institutes for research on combustion products.
- Consider only substances for which toxicological data is available and for which inhalation is the main route.
- Attune temporal and spatial resolution based on the resolution of models, measurements and toxicological exposure parameters; adjustments of methods and models may be required.
- EPA has produced an overview of all kinds of models for Total Risk Integrated Methodology
- Consider methods to assess the peak concentration retrospectively after measurements (a little) later.
- Discriminate between acute effects and effects in the long term that might not be noticeable in the period immediately after the disaster.
- Consider measurements that the public consider relevant, although the need for risk assessment is questionable.

- Consider measurements of tracers in combination with sampling methods: to analyse the entire group the tracer should be representative. BaP for PAH, for example.
- Develop assays for long-term effects.
- Evaluate the relevance of metals are relevant? Be aware of Cr6 as part of tungsten salts.
- Consider that only a limited number of RIVM emergency response people (MOD) can be involved. Hence the developments need to improve efficiency and effectiveness.
- Consider a fast, easy and effective procedure to develop a sampling strategy in the field.

These recommendations were communicated to and discussed with the various working groups and addressed as far as was feasible.

5. Selection of substances and intervals

The selection of substances was initially based on the following criteria:

- The likelihood that a substance is emitted during a calamity based on available information such as the frequency of use, transport and the critical steps of the processes of which it is part. Information was not readily available and this criterion was, in this phase, substantially based on expert judgment. The experience of the environmental emergency response group (MOD), the insights on potential high-risk situations of the RIVM Centre for External Safety (CEV), and the suggestions of the groups of experts were helpful here.
- As the assessment outcome would initially be evaluated against short-term threshold values, maximum allowable concentrations or other short-term metrics, only those substances were included for which such a value had been developed. The expertise and the information: Expertise Centre on Substances (SEC), although initially not planned, was found to be essential for constructing the list.
- Furthermore, compounds that might act as a proxy for a group of substances are preferred above exotic ones.
- As mentioned above the exposure route is limited to inhalation and hence only the substances that could follow this route are included, although the information available is not always sufficient to support this criterion.

Sources of information that were or could be consulted in further phases of the project include:

- SERIDA - Safety Environmental RIsk DAtabase (maintained by CEV – Centre for External Safety - www.rivm.nl/serida has been approved by the Dutch Commission for the Prevention of Disasters (CPR) and has the official status of CPR19. The substances in this database are selected from External Safety Reports (EVRs), the Seveso II list, the Black List of EU and Ministry of VROM and the list of the International Rhine Committee (IRC). These information sources are well documented. SERIDA contains information on 684 substances.
- Physical and chemical specifications of the substances are listed in DIPPR (approximately 1500 substances).
- Further information on the most severe categories can be found in safety reports of approximately 90 Seveso II companies. Data on substances are included.
- Company reports of Seveso II companies (approximately 280) are available stating that these companies are listed under the directive, Risk of Heavy Disasters (BRZO'99). In these reports the amount of the substances are named as being on the premises (categorized according to BRZO'99).
- Further information is listed in databases on calamities with harmful substances during the last decades, including the Accident Database van the Institute of Chemical Engineers (IChemE) and TNO Friends Database (TNO). These databases are not intended to be complete but do contain information on disasters in the Netherlands as well as abroad.
- By order of the Ministry of VROM, CEV maintains the database registering risk situations arising from harmful substances (‘Register Risicosituaties Gevaarlijke Stoffen’ in Dutch). Companies dealing with harmful substances would be legally forced to be included in this database in 2004. It is expected that information

will be included in the database only a few months after the enforcement of the 'Register decision' ('Registerbesluit') referring to the database above.

Applying the above-mentioned criteria on the data sources has resulted in a list of 31 substances. Some substances, such as carbon monoxide, nitrogen dioxide and ammonia, are quite trivial as these are also air pollutants monitored in the National Air Quality Monitoring Network run by the RIVM. Accidents involving large amounts of these substances, however, will reflect a completely different situation than the occurrence of low concentration in the atmosphere. Compounds such as benzene and formaldehyde, are often present in mixtures, and might act as proxies the assessment of exposure to these mixtures. Again, the emphasis should be on this list being a result of applying criteria on available data sources and not solely on past experience.

In general, the substances that have been selected are the ones highly likely to appear in the air after the onset of a fire or other major event. They can be regarded as indicators for many other chemicals. Obviously, these 31substances cannot reflect all possible disaster emissions. Case studies will be needed to test the usefulness of the list. One of the original aims within the RISPIEC project, was testing, but still has to be undertaken.

6. Evaluation of dispersion and exposure models

Various efforts have recently been made to develop models for air pollution dispersion and assessment of potential and actual exposure. Concentrations of air pollutants or external exposure are calculated with the use of dispersion models incorporating air quality measurements and actual meteorology. The relationship between the actual (external) exposure and the internal dose in the target organ is dependent on a large number of factors such as the agent/chemical, and the health status and age of the individual. The last step in the development is a refinement in exposure assessment that, particularly for aerosol, is critical in the assessment of the risk of a given individual.

The existing models for dispersion, exposure and dosimetry were evaluated on their capacity to estimate concentrations in the various micro-environments, personal exposure (external concentration and internal dose) at any given time (hours instead of days) after the onset of an event and at high geographical resolution (tens or hundreds of metres rather than kilometres). Both RIVM models and those developed elsewhere were assessed for their usefulness in the rapid risk assessment approach. Subsequently, a list of essential (temporal and geographical) input data was made and the strength and weaknesses of these models evaluated.

6.1 Dispersion models

Concentrations of external exposure to air pollutants are with dispersion models using air quality measurements and actual meteorology. Concentrations in the various micro-climates will be estimated on the basis of measurement obtained and model calculation results using various models for infiltration and filtering of ambient air to these micro-environments. Both models used at the RIVM and models developed elsewhere are assessed for their use in this risk assessment approach.

As the development of dispersion models suitable for high temporal resolution (hours) forms part of another RIVM project, no initiatives were developed to have these models modified within this project; this is because the objectives of this other project were similar to the RISPIEC objectives.

Figure 4: Fire at tire production site in Naarden.

Table 1 overviews the available models. The two models, Phast and Safer, are both promising but require substantial work. Both models can deal with a broad range of calamity types, both particulates and gases released during fires, explosions and more moderate emissions. The spatial resolution is more than sufficient; the temporal resolution is still to be explored. Safer, in particular, offers the possibility of applying the most up-to-date meteorological information in an automatic fashion incorporating data from a mobile meteorological station. Furthermore, Safer enables back calculation that will allow the emission rate to be estimated on the basis of based actual measurements. Another important feature for both models is the possibility of links with geographical information systems (GIS) that exhibit the evaluation of dispersion calculations directly on the map of the surroundings of the calamity site. Both the models Phast and Safer, as well as Aloha, offer the option of calculating concentrations in micro-environments, and in doing so, provide data for the input of exposure assessment models.

Although in use at RIVM for some time, the other available models (PUF-kort and OPS-kort), have significant disadvantages that ruled them out as RRA tools Nevertheless, the two models of interest still require substantial work.

6.2 Population exposure models

A substantial number of exposure models were found in the literature and/or though personal contacts with the research organizations: MENTOR/SHEDS, APEX, AIRPEX (RIVM), pCNEM, SHEDS, pNEM, REHEX, SHAPE, Beam, CPIEM and HAPEM. These models were evaluated according to the objectives of the project (Table 2).

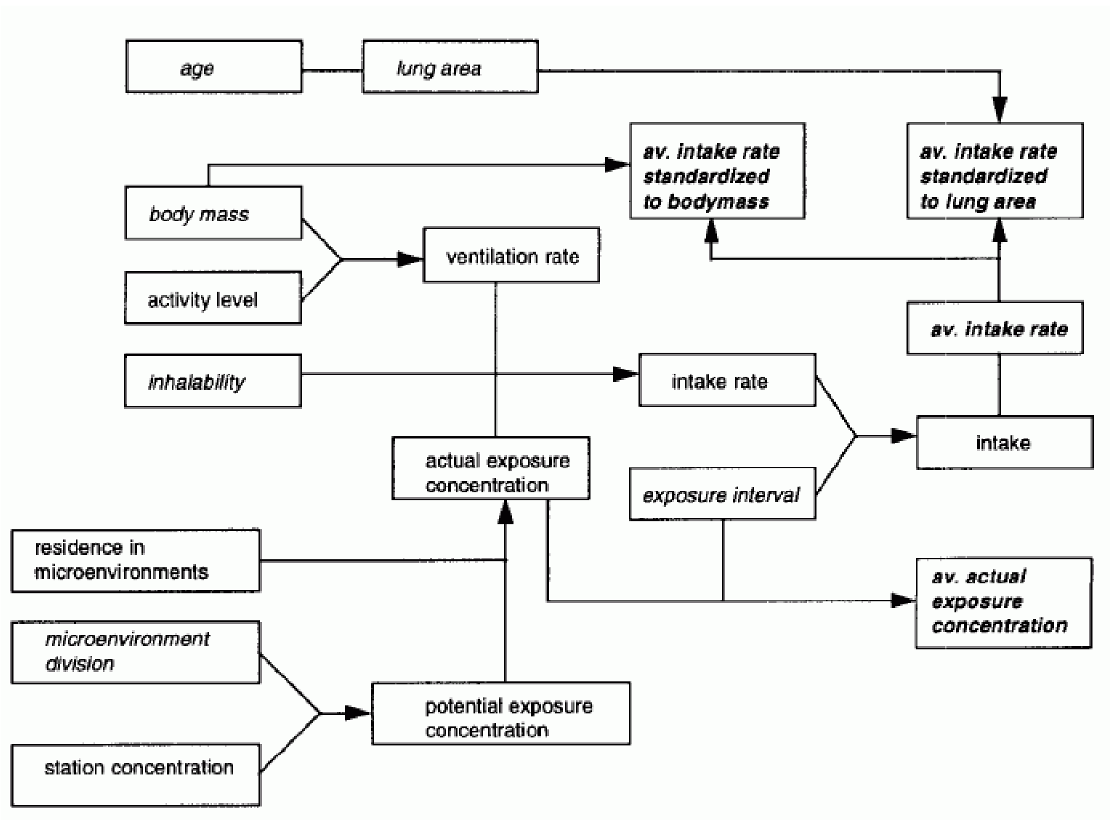

Figure 5: Associations between different model elements in the calculations of primary exposure measures of individuals.

The MENTOR/SHEDS population exposure model is the only one adapted for application in case of emergencies. The model is used in the framework of the WTC-EXIS system to support assessments of population exposures and doses for contaminants released from the World Trade Centre (WTC) collapse on 9/11/2001 and the subsequent fires following the collapse. The main differences between MENTOR/SHEDS and other models (see Table 2) are the activity event-based temporal resolution, multi-scale applicability and multiple exposure routes. Although not applied to modeling exposures related to emergencies, the APEX-model is well-documented and readily available. APEX is up-to-date and represents the result of further development of pNEM models. Some adaptation is needed to be applicable for emergency exposure modelling. The AirPEx model was developed at RIVM explicitly for the Dutch situation. The model does not address variability in time and needs significant changes. The PCNEM model is a platform accessible via Internet, which allows users to build their own applications. Although very flexible, the usefulness of calculations performed is doubtful as the accessibility of Internet becomes a critical factor.

Activity patterns are relevant for assessing the dose. Activity patterns describe the location where individuals find themselves at a certain times and what kind of activity they perform. The exposure and dose can be estimated in combination with the actual air pollution concentration. Activity patterns have been constructed for a number of models. An activity pattern for the Dutch population was constructed in a survey in 1995 to model the exposure in a normal life situation. A 24-hour diary (temporal resolution 15 minutes) was developed for this, as well as a list of questions on the person and his/her household. In the diary the respondent keeps track of the micro-environment in which he/she resides (7 categories), his/her activity (20 categories) and the level of exercise (5 categories) of this activity. The survey was split into three parts: a summer survey, a winter survey and a survey carried out during an air pollution episode in summer when the maximum daily temperature was above 25^{o}C. A weighting procedure was employed in each survey to compensate for deviations of the sample populations with respect to age and gender from the data in the Dutch Mini-Census of 1994. This procedure yielded a demographic weight for each person in the sample populations. The population activity pattern survey was carried out in 1995 (9 years ago then). There were time budget studies TBO (‘tijdbestedingsonderzoek’) in 1995 and in 2000. Even though these studies lack exposure-related questions, comparison of TBO data from 2000 with the TBO data from 1995 might enable some updating of the Intomart survey on some points. The TBO might also need to be updated, considering that it is already 10 years old.

In emergencies, however, behaviour of people will differ. Depending on the perception of the conditions, the nature and quality of the information that reaches people nearby the calamity, the assumed possibility to escape the area and the intent of and opportunity for people to come closer to the disaster to watch it. All this makes the applicability of the data describing the normal life questionable.

There is a need for knowledge on activity patterns during emergencies to be able to apply exposure models based on activity pattern, whether or not probabilistic model distributions (mean and standard deviation of activity patterns of certain population cohorts) are used or individuals.

Table 1: *Overview of dispersion models*

	Phast	Safer	Aloha	PUF-kort	OPS-kort
Type of catastrophe	Fire, evaporation, emissions, explosions, leakage etc. Indoor air	Fire, evaporation, emissions, explosions, leakage etc. Indoor air	Fire, evaporation, emissions, explosions, leakage etc. Indoor air	Brand, evaporation, emission	Brand, evaporation, emission
Compounds	Gases, aerosols, liquids, database of 1000 substance	Gases, aerosols, liquids, database of 1000 substance	Gases, liquids	Gases, aerosols	Gases, aerosols
Missing compound			Aerosols	Heavy gases	Heavy gases
Resolution	< 10 km, > 10 m	< 10 km, > 10 m	?	< 60 km, > 2 km	< 25 km, > 10m(?)
Min. computation time	?	?	?, (max. 1 hr)	?	1 hr
Input					
Output	Concentration, dose	Concentration, dose	Concentration	Concentration	Concentration
User interface	Windows	Windows	None-windows, reasonable in use	Pm (npk)	None
Link with geographical information systems	Esri	Esri	No	PM	No
Import of meteorological data	By hand	By hand or online with mobile meteorology station	By hand	Hirlam or by hand	By hand
Developer	Extern/Rivm	Extern	Extern	RIVM	RIVM
User at RIVM	CEV	-	MOD	± LSO	- ('LLO')
Validation	Oke	Oke	?	Pm	Moderate (?)
Advantages	Connection with RIVM-CEV, many options	Back-calculation, locale online meteo	In use at RIVM-MOD, simple	Connection with RIVM-LSO, simple,	Simple
Disadvantages	Not known how to adjust	No RIVM licence yet /adjustments need to be outsourced?	No deposition, no GIS application, external	Restricted number of substances	Substantial in-house development is needed, including a user-friendly interface

Table 2: *Population exposure model summary in order of adequacy for our purposes*

Model	Exposure estimate time scale	Character-ization of the high-end exposures	Typical spatial scale/ resolution	Temporal scale/ resolution	Probabilistic model*	Commuting patterns	Exposure routes	Potential dose calculation	Physiolo-gically based dose	Variability/ uncertainty
MENTOR/SHEDS	Activity event-based	Yes	Multiscale/ Census tract level	A year/ Activity event based time step	Yes	Yes	Multiple	Yes	Yes	Yes (various tools)
APEX	Hourly averaged	Yes	Urban areas/ Census tract level	A year/ 1 hour	Yes	Yes	Inhalation	Yes	No	Yes
AIRPEX (RIVM)	Hourly averaged	Yes	Dutch National/Census tract level	A year/ 1 hour	No	Yes	Inhalation	Yes	No	No
pCNEM	Hourly averaged	Yes	Urban areas/ Census tract level	A year/ 1 hour	Yes	Yes	Inhalation	Yes	No	Yes
SHEDS	Hourly averaged	Yes	Urban areas/ Census tract level	A year/ 1 hour	Yes	No	Inhalation	Yes	No	Yes
pNEM, REHEX	Hourly averaged	Yes	Urban areas / Census tract level	A year/ 1 hour	Yes	Yes	Inhalation	Yes	No	Yes
SHAPE, Beam	Hourly averaged	Yes	Urban areas / Census tract level	24 hours/ 1, 8 hours	Yes	Yes	Inhalation	Yes	No	Yes
CPIEM	Hourly averaged	Yes	Primarily indoor	24 hours/ 12, 8, 1 hour	Yes	No	Inhalation	Yes	No	Yes
HAPEM	Annual averaged	No	From urban to national/ Census tract level	A year/ 1 hour	No	Yes	Inhalation	No	No	No

* Yes – random samples from probability distributions, no – point estimates;
**nss – non-steady-state, ss – steady state, mbe – mass balance equations, lr – linear regression, fosa – flexibility of selecting algorithms, iacm - indoor air chemistry module

7. Discussion and conclusion

The reported data represent only the beginning of the trajectory which the developments of the various units of the institute would need to follow in the near future to improve their response to the requirements for one of the core functions of the institute.

The approach to prioritize the developments based on the amount, the application and the risk of was found to be the most sensible. Following the subsequent steps to list these substances showed that many of the inventories are still incomplete or still have to be developed.

The inventory of dispersion models, as well as exposure and dosimetry models show that only a few promise to produce results that can be applied in the RRA. As many other organizations have defined their needs for these models, more appropriate models are expected to become available in the near future.

One of the objectives of the project was to develop analytical methods for swiftly producing data that could be used to assess concentrations of various pollutants. The work in this field is far from complete and for that reason is not included in this report. As some methods need be used in the current MOD activities, some of them will be taken on for development, however, not in the concerted way that would make this work optimally effective.

The decision to end the project just after the inception phase was primarily based on the evaluation of the objectives of the project itself. The need for information on exposure of people close to the location of the disaster, and the possibilities of arriving at an adequate risk assessment were questioned. This was illustrated with two examples: the explosion of the nuclear reactor in Chernobyl and the fire in a chemical waste deposit ATF in Drachten (NL).

The need for information on the exposure of people near the disaster is explained in general in the introduction of this report and stressed regularly in the aftermath of large accidents. Settlement of the Bijlmer airplane crash has, for example, lasted so long because no adequate exposure estimate could be given that was not disputed by the potentially exposed people. It was not possible to distinguish between people who were exposed to the emissions of the fire itself, or to the materials transported in the cargo compartment of the plane, and the people exposed to the dramatic event of a plane crash in a densely populated urban area.

Authorities have learned since then, especially when the Enschede fireworks explosion happened, to launch a large-scale survey soon after the explosion, and to assess the exposure of the relief-workers as well as the general public to firework emissions.

Regarding the Chernobyl nuclear reactor disaster, it was stated that measurements near the source in Chernobyl would have been of no use. For two reasons the authors do not agree. Firstly, accurate source strength information would have better facilitated the dispersion model exercise (at that time carried out by the such instances as the Laboratory for Air Quality of the RIVM) and would have improved

the assessment of the risk for the European population. For the population close to the reactor accurate source strength estimates would have been of huge relevance as this information also would have resulted in the necessary measures in Ukraine.
The fire in the chemical waste deposit ATF in Drachten was the other example mentioned. The information on the occurrence and fate of the emissions of this fire gathered shortly after the RIVM was requested to assist was still not sufficient. The ongoing concern of the population in Drachten and its surroundings stress the relevance for exposure information and, consequently, the need for techniques and procedures, as focused on in this project.

An even more revealing example illustrating the need for adequate exposure information forms the collapse of the World Trade Towers in New York on 11 September 2001. Measurements of airborne material, particulate matter and various gaseous substances, were started only ten days after the disaster, and therefore could only partly fulfil the information need to assess the exposure of relief-workers and general public for an adequate risk assessment. Presently, substantial effort is given to modelling the collapse itself and the dispersion of debris, and airborne pollutants, to improve the insight in the exposure of people and the possible health risk on the long term.

In a number of national and international institutes groups have been formed to develop concepts and tools for exposure assessments in the case of disasters, accidental mishaps or terrorist attacks, in response to the awareness of the requirement to direct risk reduction and protective measures in the most effective way once a disaster happens.

The authors fully concur with the reviewers' statement about how ambitious the objectives of this project were, and refer to the 2005 mission statement of the RIVM to support their reaction.

The termination of this project also brings the development and improvement of approaches, concepts, techniques and procedures for rapid risk assessment to a halt in the concerted way intended in the project setup. Nevertheless, in the authors' opinion, there is still a need for the products emerging from this project; these will be instrumental in realizing RIVM's mission. Still, the concepts and limited databases developed may prove useful in institute initiatives taken in the near future.

Annex 1: RISPIEC poster