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Rasmussen, Birgitte; Grønberg, Carsten

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Accident Knowledge and Emergency Management

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Birgitte Rasmussen, Carsten D. Grønberg

Risø National Laboratory, Roskilde, Denmark
March 1997

Abstract. The report contains an overall frame for transformation of knowledge and experience from risk analysis to emergency education.

An accident model has been developed to describe the emergency situation. A key concept of this model is uncontrolled flow of energy (UFOE), essential elements are the state, location and movement of the energy (and mass). A UFOE can be considered as the driving force of an accident, e.g., an explosion, a fire, a release of heavy gases. As long as the energy is confined, i.e. the location and movement of the energy are under control, the situation is safe, but loss of confinement will create a hazardous situation that may develop into an accident.

A domain model has been developed for representing accident and emergency scenarios occurring in society. The domain model uses three main categories: status, context and objectives. A domain is a group of activities with allied goals and elements and ten specific domains have been investigated: process plant, storage, nuclear power plant, energy distribution, marine transport of goods, marine transport of people, aviation, transport by road, transport by rail and natural disasters. Totally 25 accident cases were consulted and information was extracted for filling into the schematic representations with two to four cases pr. specific domain.

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Appendix : Accident and specific domain descriptions

1. Introduction

1.1 Background

An accident raises questions like: how did it happen, was it equipment failure or human error, or was it avoidable ? In addition to worrying about losses and other consequences, it is essential to draw knowledge out of it, formulate experience for use by hardware designers, system designers and risk managers.

Emergency managers and emergency personnel generally gather accident knowledge from three sources:

- personal experience
- education and training
- contingency plans and procedures,

and the prevailing forms for representing accident knowledge are the scenario and case story. When pilots or nuclear reactor operators are trained with training simulators, these can reproduce malfunctions and critical conditions in order to train responses to selected accident scenarios. Training of emergency managers can be conceived as an expansion in two directions compared to traditional simulator training: both the system dimension and the accident dimension are stretched considerably. Alternatively, emergency manager training can be conducted with emphasis on rehearsing the plans, where the reactor or aeroplane is substituted by "an emergency".

Education and training of emergency managers will have two main orientations: 1) organisations and society, 2) accidents. Generally speaking, accident investigations can be used to reduce the number of unknown parameters in future accidents, by developing appropriate and flexible emergency organisations. Emergency managers have to deal with hazard identification, prevention, risk ranking and other risk management risk issues, with the additional condition, that decisions are to be made under severe time stress and sometimes in immediate danger. Even a modest improvement in analysis tool and accident knowledge for the emergency manager is worth looking for, remembering that such tools have to be rather crude, i.e. simple and reliable.

1.2 The MEMbrain project

MEMbrain is an European project inside the framework of EUREKA running 1993-1998. The aim of the project is to define and implement a standard European software and hardware platform for Major Emergency Management which can be adapted for different applications (e.g. local, regional) and different activities and events (e.g. chemical industrial accidents, natural disasters).

It is of crucial importance that the development and planning of training scenarios is based on a good representation of real emergencies and typical accident processes. A study of training situations (Miberg 1994) has shown, that in many cases, the planning and goal for a training session are rather loose: a) the specific abilities to be trained are not precisely defined, b) training effect is not measurable.

The following framework shall support the systematic production of input to an accident database applicable for generation of training scenarios ensuring that all relevant events and elements are incorporated in the training scenarios and that all relevant personnel and organisations are participating in the training session. The present work, which is a part of the MEMbrain project, covers the following activities:

- systematically extracting and presenting accident knowledge from 25 accidents, representing the main accident types
- developing models to support both the case work and the later structuring of the extracted knowledge for training purposes
- devise a formulation of the general accident knowledge collected that can function in a scenario generator or other type of accident bank for training use.

1.3 Survey of the study

The overall goal of the work has been to develop a model focusing on the transformation of knowledge and experience from risk analysis and accident investigation in the development of incident and emergency scenarios, which subsequently could be used in the training sessions. The model seeks to investigate the operational reasons for carrying out training sessions:

- which hazards are relevant to consider ?
- which events, mechanisms and factors may have an influence on the incident course ?
- which operational difficulties may arise during the on-site emergency operation ?

It is important to stress that the developed model focus on the planning of emergency training scenarios. The model does not deal with the planning, execution and evaluation of training sessions.

The present report contains the following main elements:

- <u>Overall framework:</u> Development of a model describing a domain as a socio-technical system including structural, operational and managerial factors. The focus is on accident and emergency scenarios including characteristics of emergency operations and planning of emergency training scenarios.

- <u>Modelling the emergency situation</u>: The incident model developed places risk and objects (victims) in the centre, considering an incident as a situation with uncontrolled flow of energy, arising from loss of confinement.

- <u>Risk analysis</u>: The role of hazard identification is to establish the foundation upon which many of the safety and emergency components are built. A functional model of the domain has been chosen as basis for the hazard identification. Incident scenarios are developed which can lead to the identified potential hazards. An incident scenario consists of a sequence of loops which can have a positive or negative impact on the incident course and the emergency operations.

- Domain model: The model comprises three categories: status, context and training scenario. The status contains the list of information establishing the basis for the development of incident and training scenarios. The objective is to prepare a socio-technical description of the system including structural, operational and managerial factors and to indicate which safety and emergency aspects that will be of interest for the analysis and development work. The intention of the context is to analyse and assess the safety and emergency characteristics of the domain. The incident and the emergency scenarios are evaluated with special reference to the formulation of training objectives where an important question is: what must be learned ? Finally, in the training scenario part models and principles for training are discussed and evaluated and the training scenario is structured. It is considered how to run the training session and how the session is going to be evaluated.

- Specific domains: Domains have different characteristics which will have an important influence on the development of the course of an accident and emergency scenario which must be taken into account during the development of a training scenario and the execution of the training sessions. The following domains cover the majority of the accidents occurring in the society and for each of these detailed domain descriptions have been developed:
  - Process plant.
  - Storage.
  - Power plant - nuclear.
  - Energy distribution (reservoirs, pipeline, storages).
  - Marine transport - goods.
  - Marine transport - people.
  - Aviation.
  - Transport by road.
  - Transport by rail.
  - Natural disasters.

  For each of the specific domains about 2-4 accident case stories have been selected which are representative for the specific domain. The cases are analysed with respect to the accident events and the emergency operations. The intention with the analysis of accident case stories is to integrate the experiences gained into the specific domain descriptions.

2. Overall framework

2.1 Systems concept for incident prevention and protection

Systems analysis may be defined as the systematic application of knowledge, skills, logic and intuition to solve a problem about a system. A systems analysis procedure may pass through three basic steps:

a) Definition: Problem definition is the first and most important step which provides a basis for understanding, communication and verification. Problem definition does also include determination of the scope and objectives of the analysis.
b) Modelling: Modelling is the formal presentation of the understanding gained of the system in the problem definition step. This representation takes the form as a symbolic model of the system. It may be diagrammatic, mathematical or computerised, or often, some combination of all three. The behaviour of the system may be conveniently studied by manipulating the model rather than manipulating the system itself.
c) Evaluation: The evaluation step selects, analyses and compares alternative courses of actions. In a comprehensive study, evaluation also includes implementation of the best alternative and monitoring to ensure that expected results are actually achieved.

Any scientific investigation is essentially an iterative process, and these steps are not always followed sequentially, but more often cyclically. The modelling process may suggest refinements to the problem definitions, while evaluation may suggests revisions to the model or additions to the problem definition as illustrated in Figure 2-1 (NFPA 1991).

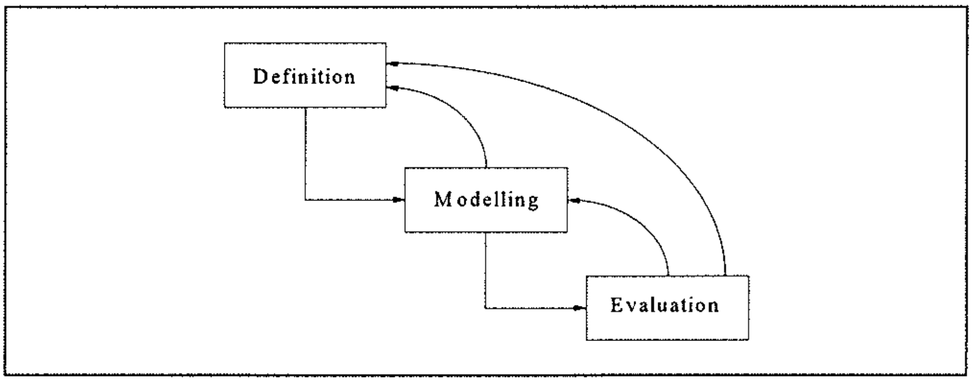

Figure 2-1. Basic steps and cycles of a systems analysis.

The systems analysis approach chosen in this report comprises the following models:

- incident model (chapter 3)
- functional model (chapter 4)
- accident scenario model (chapter 4)
- domain model (chapter 5).

2.2 Elements of the socio-technical description

During an on-site emergency operation the decisions taken by the emergency management do have a large impact on the possibilities for an efficient emergency control. The responsible organisations and the prescribed operational procedures together with the structural basis are key points in the managing of crises and emergency situations.

In short terms, the historical development of methodologies and techniques for risk analysis and safety assessment of complex systems can be characterised as a pass through three overlapping ages where the emphasis has been laid on different safety aspects. The first one was the technical ages in which the main focus was upon operational and engineering methods for combating hazards. Then came the human error age when it became apparent that human beings are capable of circumventing even the most advanced engineered safety devices. In the third age, the socio-technical age, it has been recognised that the major residual safety problems do not belong exclusively to either the structural or operational factors but they emerge from the interactions between the technical and social aspects of the system.

The socio-technical way of thinking provides a comprehensive and operational description of an activity. The objectives and elements of the socio-technical approach presented in this study have been inspired by the work carried out by Hale (1994), Reason (1990, 1991) and Berrogi et al. (1994). The scope of the proposed socio-technical approach is:

- to provide a general framework for representing an activity as a socio-technical system including structural, operational and managerial factors
- to structure the questions about the way in which the emergency situation is handled with respect to accident prevention, preparedness and response in order to search for critical events and failures
- to provide a coherent structure within which any individual/organisation can locate his/her/its role during the emergency operation
- to prepare a systematic and comprehensive description of an activity with reference to hazard identification purpose and development of incident and emergency scenarios to be used in the planning of emergency training scenarios.

The socio-technical approach is a general description of an activity and therefore by nature a culture-free framework. During the development of a training scenario and a training session for a specific emergency situation several decisions are made, reflecting the culture of the organisation and having a dominant influence on the particular execution of the training session. Examples of these decisions are:

- who is involved in what tasks
- which evaluation criteria are set
- what priorities are chosen
- how do different people in the organisation regard the tasks
- how are tasks communicated.

The way the general description of an activity will be translated into an actual training situation will differ from one organisation to another depending on its culture, size, resources, location, type of process, etc. There are more than one way to carry out an emergency operation successfully.

2.3 Decision making in emergency management

Levels of decision making

In order to understand and evaluate the behaviour of an emergency organisation during an emergency operation an important aspect will obviously be an evaluation of the decisions taken during the emergency operation, but also the decisions taken prior to the event can have a large impact on how the emergency operation is developing. According to Hale et al. (1994) levels of decision making can be structured in three levels:

- Execution level: The level at which the actions of those involved directly influence the development of the emergency operation. It concerns itself with the recognition of the incident scenario and the choice of actions to recover, prevent or mitigate the situation. The degrees of freedom present at this level are therefore limited and as soon as a situation is identified where the prescribed and planned actions are no longer thought to be appropriate, the next level is activated.
- Planning, organisation and procedures: This level is concerned with the devising and formalising the actions taken in the execution level, i.e. setting out responsibilities, procedures etc. This level makes the translation of abstract principles into concrete task allocation and implementation. Furthermore, it is the level for new initiatives, evaluation and modification of procedures, collection of new insights about accident prevention, preparedness and response.
- System structure and management system: The level is concerned with the overall principles of the emergency management system, how it is set up and maintained and how it functions. The level is activated when organisation considers that the planning, organisation and procedures level is failing in fundamental ways to achieve acceptable performance or continuing improvement of the execution level. It should be emphasised that these three levels are abstractions corresponding to three different types of feedback (correction, learning/improvement and structural (re)design)). They are emphatically not to be seen as contiguous with the hierarchical levels of the emergency organisation

Operational patterns

The extent of an incident in space and time affects the demands on the response. Many incidents can easily be overlooked by the emergency operation leader and communicated by people involved in the response. People involved in an emergency situation that is extensive in time and/or space cannot survey the whole event and have the same contact with it. Special work is need to structuralize the event, i.e. to find out what has taken place and what that implies (Fredholm 1991).

In a major operation the connections between the demands of the accident and the resources used consist of a lot of simultaneous decisions cycles in a more or less effective interplay. Different individuals manage these different decision cycles. Chiefs of sectors in the damage area work with the decision cycles of the intuitive direct command and control. Other chiefs work with the long-termed command and control. The co-ordination between all these decision cycles is an important factor.

The decision problems in emergency management can be seen in different strata (Fredholm 1996):

a) The first stratum is the concrete decision making. The spans of time consists of seconds and minutes. The category concerns the most common and ordinary turn-outs. It is possible to observe the situation directly and the situation is limited. The resources used are locally available. The knowledge of the Fire Ground Commander is mostly enough and there is no need for other experts.
b) The accident can be wider and more complicated but still possible to handle for the Fire Ground Commander. The situation can still be handled with resources from the local organisations but maybe the fire ground has to be divided into two or more sections. The Fire Ground Commander has to handle decision problems in one more stratum, namely the locally limited decision making.
c) The next category of accidents demands competence of more than one expert and there will be more of negotiation in the decision making. The spans of time and space are hours, days and maybe weeks. The used resources are from several organisations. The stratum in which the decisions occurs is the limited and combined managed decision making.
d) The next category of accidents demand intervention of local governmental authorities. The accident consists of a large damage area or influences the society in different ways. A lot of different resources are needed. The added decision problems stratum is the local governmental decision making.
e) If the accident is very complicated or wide, the regional authorities have to intervene. The regional governmental decision making is added.
f) If the accident/disaster is still more complicated or influence the society in important aspects the central governmental authorities have to intervene. The central governmental decision making is added.
g) The stratum of the international decision making can be initiated. During the last years such situations have occurred (e.g. the Chernobyl disaster, the fire on the ferry "Scandinavian Star", the capsize of the ferry "Estonia").

The decision process can in every level be described and analysed in the following dimensions: direction of decision making, intention, span of time, span of space, complexity, resource relation, way of decision making, structure of co-ordination, conception of context, anticipatory conception, conflict pattern, management of information, organisational context and technical context.

One characteristic difference between these levels is the time-frame in which the emergency operations are done. For the concrete working level the operative perspective is in minutes and hours. At the local level of co-ordination an overall structure must be built up for the concrete operations. These operations may well have a perspective of hours or days. The regional level is characterised by a time-frame of days and weeks. The national level has an even longer time-frame (Fredholm 1991).

Fredholm (1996) has formulated a model for a tactical ideal: "Rescue tactics should be formed as a combination of measures which are as optimal as possible, in time and space, applied locally and strong in relation to the situation". The problem of discussing an ideal performance of emergency management is complicated. The general doctrine for any firefighting and rescue operation is to prevent and limit harm to people, property and environment. Four basic rules of priority have been written down by Fredholm (1996) forming an intuitive foundation of choices made by the Fire Ground Commander:

1) Saving lives goes before saving property.
2) Attack is more demanding than containment.
3) Contain first - then eliminate danger source.
4) The earlier the response, the better the result.

Starting with the general doctrine and rules of priority the commander decides upon basic tactical aims. The commander must work with four problem dimensions which are:

a) to identify rescue problems
b) to formulate objectives, objective hierarchies, rescue hierarchies and their coordination
c) to predict development
d) to handle social interaction and experiences.

Choices and actions taken in one dimension will influence the others and in practice the four dimensions are dealt with in an integrated way.

3. Modelling the emergency situation

3.1 Uncontrolled flow of energy

An accident model was developed to describe the emergency situation. A key concept of this model is uncontrolled flow of energy (UFOE), essential elements are the state, location and movement of the energy (and mass). A similar concept can be found in the model proposed by Koornneef and Hale (1995) for modelling of accidents at work. The main difference between the two models is that the UFOE model describes major hazards and the emergency situation focusing on hazard control efforts and basic ways of fighting UFOE's towards vulnerable objects.

The model is a simplified representation of real life's complex incident courses. At the conceptual level a UFOE is defined as the driving force of an incident and it is important to stress that the concept shall be interpreted comprehensively. A UFOE can be e.g., an explosion, a fire, a release of heavy gases, loss of carrying power (aircraft). As long as the energy is confined, i.e. the location and movement of the energy are under control, the situation is safe but loss of confinement will create a hazardous situation, that may develop into an incident.

3.2 Incident model

The incident model is presented in Figure 3-1. Any accident can be described as one or more sequences of energy transfer, influenced by more or less successful confinements. The incident model is explained as follows:

- A confined amount of energy can constitute a hazard source. If sufficient energy is present, the prerequisites for an accident is present. In order to prepare the safety measures and the emergency plan, it is essential to ensure that all hazard sources of the activity are identified and evaluated.
- Central factors of the incident model is confinement and loss of confinement. Confinements involve containing systems and control systems. In order to control the hazard source possibilities for confinements must be identified and realised. If the installed confinements are lost with respect to the safety-critical processes, the incident process has already begun.
- The combination of sufficient energy and inadequate confinement results in uncontrolled flow of energy (UFOE).
- If a vulnerable object is exposed to an energy flow without sufficient barriers then the accidental consequence becomes a fact. There is a near-miss incident if a UFOE occurs without hitting a vulnerable target. Vulnerable objects can be human beings, environment and property (economic entities).

As it appears from the incident model, Figure 3-1, the development of an incident does not depend entirely on the properties and quantities of the substances involved. Structural, operational and managerial factors have a large impact on the transfer of energy. These are pictured as "socio-technical conditions" in the figure. A special part of the socio-technical conditions influencing the development of the incident course is the "Control efforts" established, which can be divided into hazard control and emergency support. The reason is that the control efforts have a different character before and after loss of confinement. As long as the confinement is maintained the control effort can be characterised as hazard control, i.e. that all hazards have been identified and are brought under operational control. This implies, that safety functions and responsibilities have been specified. If there is a loss of confinement creating an UFOE, the emergency organisations and measures are activated. The role of the emergency organisations is to try to control the UFOE and to limit the damage the UFOE may cause on vulnerable objects.

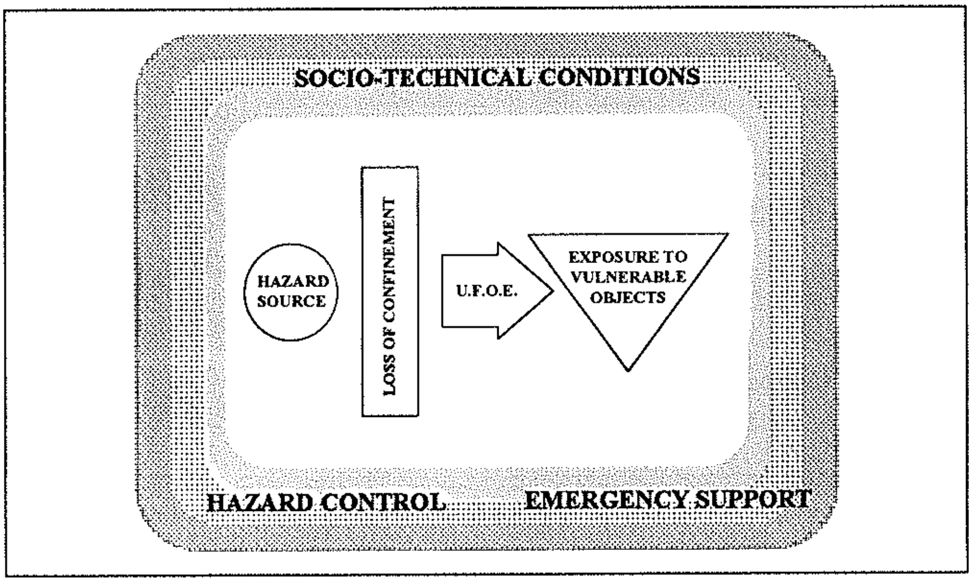

Figure 3-1. Incident model.

Centred around the triad of hazard source, UFOE and vulnerable objects, a set of universal emergency measures have been formulated, see Figure 3-2.

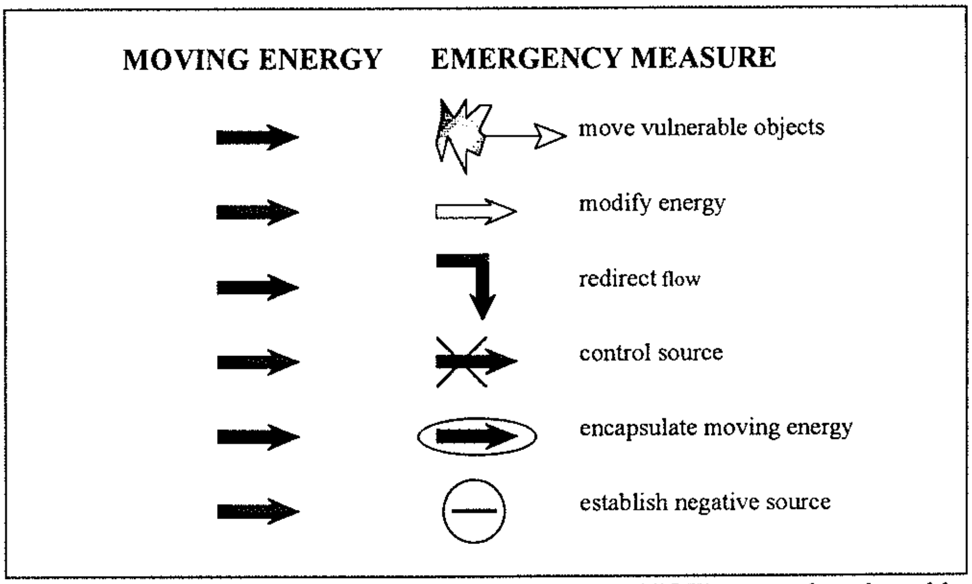

Figure 3-2. Basic ways of controlling or fighting UFOE's towards vulnerable objects.

Examples of the basic ways of controlling or fighting UFOE's towards vulnerable objects are:

- Move vulnerable objects: evacuate plant staff, evacuate neighbours, stop traffic to area, remove valuable objects.
- Modify energy: water curtain, extinguish fire.
- Redirect flow: lead water from fire fighting away from sensitive areas, collect water from fire fighting (portable spill basins), build interimistic dams.
- Control source: extinguish fire, cover leak.
- Encapsulate moving energy: cover with foam.
- Establish negative source: lead spills to sewer, add chemical agents that react with dangerous substances

The development of an incident course can be momentary, short- or long-lived. Of crucial importance for a successful fighting of the UFOE is a throughout understanding of the dynamic behaviour of an incident and emergency course. Fredholm, 1991, distinguishes incidents as static or dynamic. A dynamic incident develops the whole time and becomes progressively worse if no actions are taken. A static incident does not change once the initial event has taken place. A static incident can be stable or unstable where a stable situation is characterised by all parts being in stable equilibrium, and an unstable that changes can take place suddenly. The division into dynamic and static incidents may seem arbitrary and it can be difficult to make a clear distinction, e.g. medical conditions are obviously dynamic events even at a static incident. The emergency requirements depend on whether the incident is dynamic, static and stable, or static and unstable. A dynamic incident is the most difficult to deal with. At an unstable static incident the operations must be shaped to ensure that the unstable equilibrium is not disturbed.

An incident course is a continuos occurrence in time and space which roughly speaking starts with loss of confinement and ends with the exposure of vulnerable objects. Some of the actors, e.g. the plant staff, can be involved in the whole of the incident course and other actors, e.g. the fire brigade, may not be called until the UFOE is emerging. It is important to stress that as an incident course is a continuos occurrence, the success of the emergency support will depend on the history of incident.

4. Risk analysis

Risk management involves the systematic identification, evaluation and control of potential losses that may arise in existing facilities/activities of the society from future events such as fires, explosions, toxic/radioactive releases or natural disasters. Whether resulting losses are measured in terms of direct costs, impacts on employees and/or the public, property and/or environmental damage, lost business, penalties or liabilities, the possibility of experiencing such losses is considered a risk. Even when effective review systems have been used to "design out" many risks, there will still be a residual risk. Corporate managers must inevitably face these residual risks in dealing with the everyday operation of the facility/activity and with the long-term planning of new ventures (AIChE 1989).

In the planning of emergency training scenarios with reference to a specific domain or activity important topics from the field of risk analysis are:

- Hazard identification determining the hazards associated with a given activity or domain.
- Determination of the events and event sequences leading to the hazards and the measures taken to control/mitigate them. It is important to see an accident and the accident response as a sequence of events as each individual event has an impact on the development of the accident course.

4.1 Hazard identification

The role of hazard identification in risk and emergency management is to establish the foundation upon which many of the safety and emergency management components are build. In (Rasmussen & Whetton 1993) a framework that has been developed to represent a process plant as a socio-technical system. The method includes structural, operational and managerial factors and is intended to be used for plant level hazard identification to identify critical areas and the need for further analysis. It is anticipated that this approach also will be useful for high level hazard identification of a domain/activity.

The model follows a general framework as indicated in Figure 4-1. The basic idea is that a set of functions link together hardware, software, operations, work organisation and general management aspects. The principle of functional modelling is that any aspect of the domain/activity can be represented by an object based upon an Intent or goal and associated with each Intent are Methods, by which the Intent is realised, and Constraints, which limit the Intent. The Methods and Constraints can themselves be treated as objects and decomposed into lower-level Intents (hence the procedure is known as functional decomposition), so giving rise to the method's hierarchical structure.

Development of the hierarchical structure proceeds as follows: A starting point, F0 is chosen. At the next level (level 1) the top function is decomposed into its main constituent elements, say F1, F2, F3. The functional decomposition is continued and refined at the subsequent levels until an appropriate level of details has been achieved. This principle is illustrated in Figure 4-1. The basic idea is that a set of functions link together structural, operational and general managerial aspects. The principle of functional modelling is that any aspect of the system can be represented by an object based upon an Intent or goal and associated with each Intent are Methods, by which the Intent is realised, and Constraints, which limit the Intent. The Methods and Constraints can themselves be treated as objects and decomposed into lower-level Intents (hence the procedure is known as functional decomposition), so giving rise to the method's hierarchical structure, (Rasmussen & Whetton 1993).

A diagrammatical model is presented in Figure 4-2, which follows the usual conventions of SADT methods of systems analysis (Structured Analysis & Design Techniques).

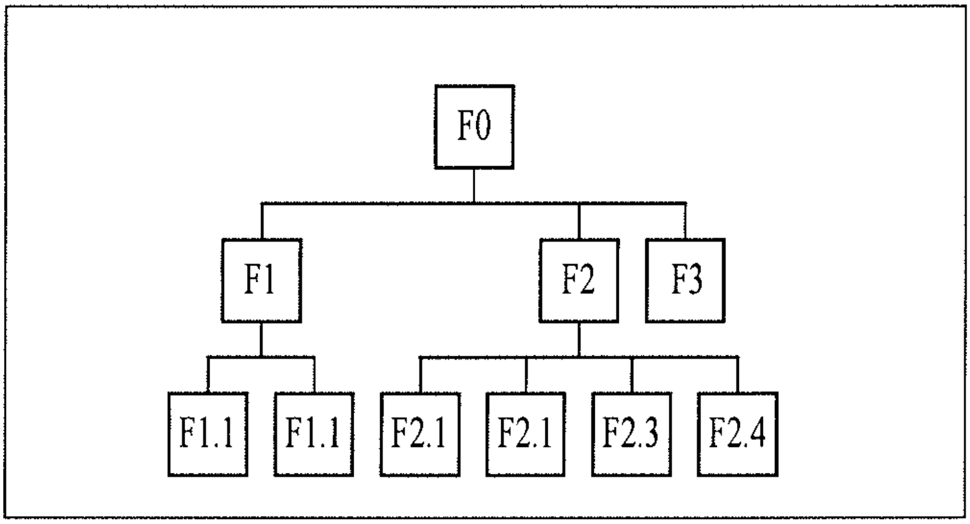

Figure 4-1. Functional description of an activity as a hierarchy of functional objects.

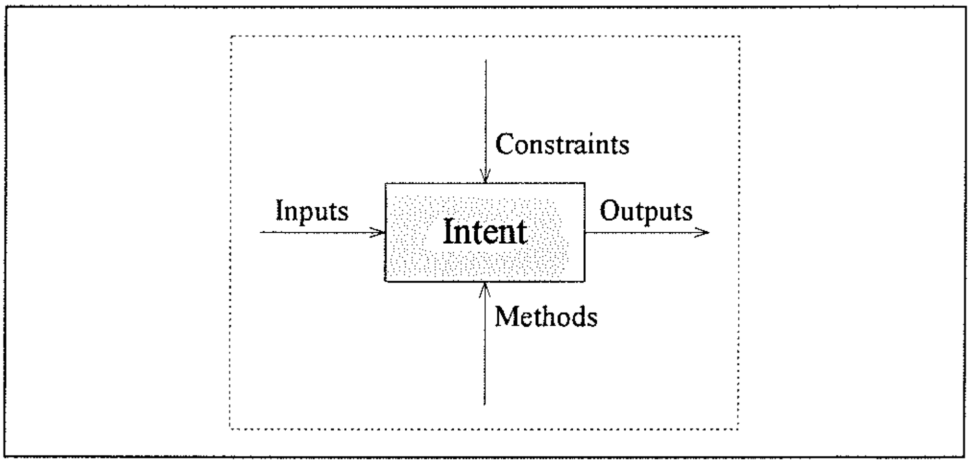

Figure 4-2. Diagrammatical functional model.

The model contains the following objects:

- Intents representing the functional goals of the specific plant activities in question.

- Methods representing items (hardware, procedures, software, etc.) that are used to carry out the Intent or operations that are carried out using those items.
- Constraints that describe items (physical laws, work organisation, control and protective systems etc.) that exist to supervise or restrict the Intent.
- Inputs are the necessary conditions to perform the Intent and the link to the previous Intent. Inputs can be either transformed or used during the performance of the Intent in order to produce the Outputs.
- Outputs are the outcome produced by the Intent and the link to the subsequent Intent. Outputs can include desired products, by-products, waste products and unwanted outcomes.

Standard methods and constraints

Methods and Constraints are objects related to a specific Intent. Constraints comprise activities, installations or subsystems that restrict or control the Intent. Generally speaking. Constraints can be equipment, supervision and/or management. Methods comprise hardware (e.g. chemicals, equipment) used and procedures or operations carried out to realise the Intent.

It is impossible to prepare a complete list of Methods and Constraints relevant to the functional model of a chemical storage facility, but Table 4-1 contains some high level standard Methods and Constraints, respectively, which is recommended always to consider during the development of the chemical storage facility model.

Table 4-1. Standard Methods and standard Constraints.

Intent		Storage of chemicals
Methods	Safety	Alarms (e.g. gas, smoke) Fire engines and equipment
	Operation	Co-ordination of activities Safety culture Maintenance and repair Construction Inspection Manuals, procedures and instructions
Constraints	Safety	Prevent fire ignition Manage fire Manage exposure Protect storage from external damage
	Operation	Logistics Inspection and supervision Manuals, procedures and instructions

4.2 Scenario model

The purpose of hazard identification and hazard evaluation is to identify possible accidents and estimate their consequences and frequency. For this purpose, an accident is defined as a specific unplanned sequence of events - the incident and emergency scenario - that has an undesirable consequence. The first event of the sequence is the initiating event. Conceivably the initiating event could be the only event, but usually it is not; usually there are one or more events between the initiating event and the consequence. These intermediate events are the responses of the system and its actors to the initiating event. Different responses to the same initiating event will often lead to different accident consequences. Even when the consequences are the same, they will usually differ in magnitude (AIChE 1985).

An incident scenario can be prepared on basis of the incident model, but the scenario structure may differ from scenario to scenario. An incident scenario consists of a sequence of loops which can have a positive or negative impact on the incident course. On the one hand each individual loop represents an opportunity to take actions (preventive or protective) to avoid further development of the incident course or to reduce the impact caused by the UFOE to vulnerable objects (human beings, environment and property). On the other hand failures and insufficient actions during design, operation and emergency are key elements to worsen the situation. The number of loops of an incident scenario will depend on the complexity of the activity and the level of detail necessary to describe a scenario will vary from activity to activity. The scenario model is presented in Figure 4-3.

The starting point of the incident and emergency scenario is the description of the confined hazard source. One single loop is a sequence of three successive elements: FAILURE → EFFECT → MEASURE. These elements can have different meaning in different areas of applications. To define the elements in an unambiguous way covering all incident and emergency situations is an insoluble task. The following characteristics can be given:

- Failure: not intended condition or event.
- Effect: consequences, impact, change of state, change of condition. An effect can initiate a new loop (domino effects, failure propagation).
- Measure: protective, preventive, operation, equipment, decision, alarm.

The term "loop" is also difficult to put into one single unambiguous definition. A loop or a sequence of loops of an incident and emergency scenario will often have different characteristics and impact on the incident course which can be illustrated as follows:

- loops can occur at different locations
- loops can occur at different times
- the duration of a loop can vary significantly
- the causes initiating the loops can be common or independent
- more than one cause might be necessary to initiate a loop
- loops can have a direct or indirect impact on each other
- loops can be totally independent
- loops can follow as a sequence - one after another.

For an activity it will normally be sufficient to develop a limited number of scenarios covering the typical hazards, consequences and emergency situations. It is important that the scenarios cover internal as well as external occurrences and responses as the incidents, origin, history and course will have an impact on the possibilities for a successful emergency operation.

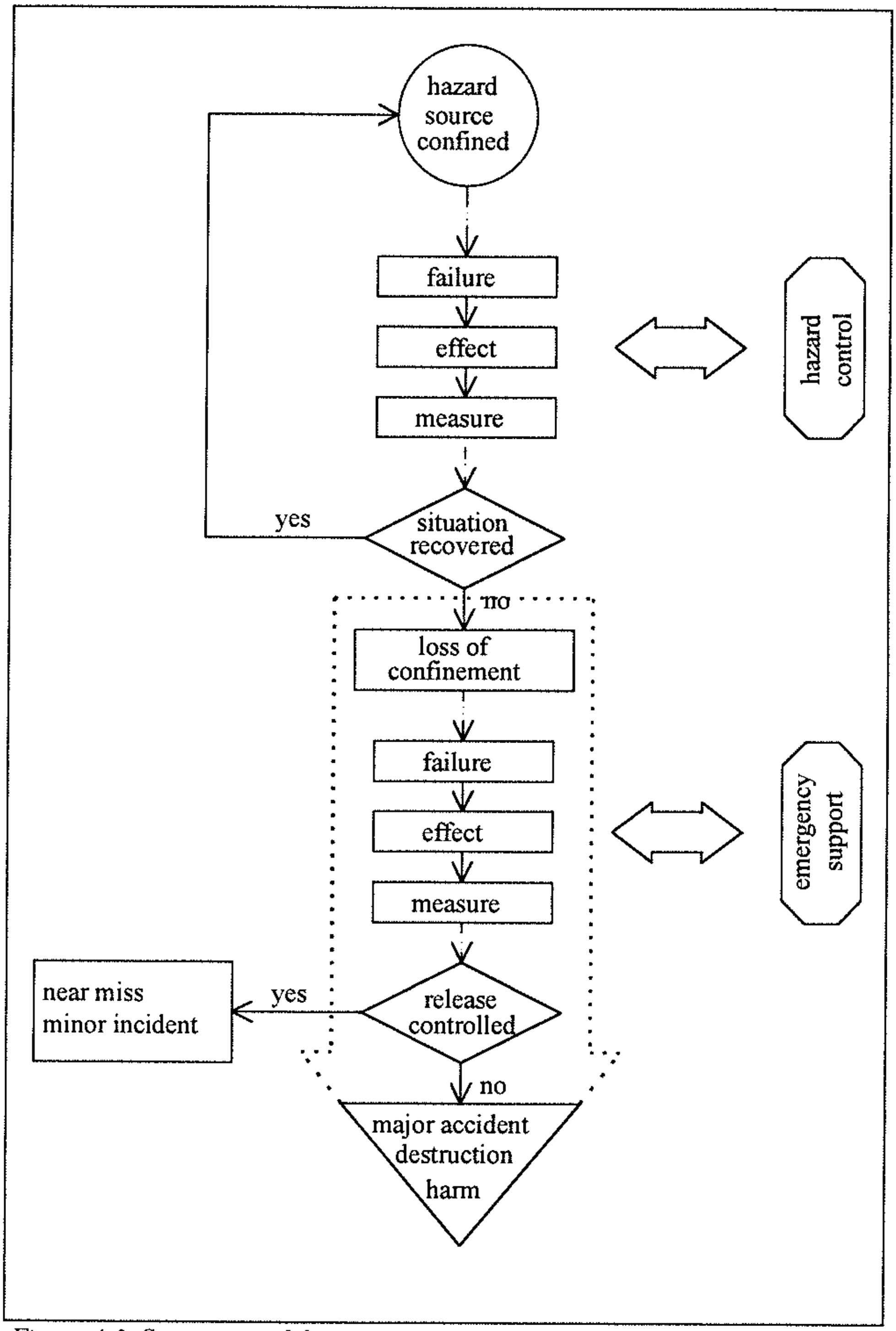

Figure 4-3. Scenario model.

A scenario can be presented in a graphical or tabular form. Table 4-2 contains a simple example of the scenario model applied on a chemical storage facility fire.

Table 4-2. Chemical storage facility fire scenario.

SCENARIO MODEL			
loop	**failure**	**effect**	**measure**
0	-	-	storage conditions, smoke/gas detectors and alarms, packing materials, storage facility
1	insufficient storage tests, temperature too high	wrong storage conditions, decomposition, heat generation	smoke detection
2	smoke detection too slow	escalation of decomposition, damage to packing materials	fire alarm
3	release of burning chemicals	domino effect, ignition of part of the storage	on-site emergency operation (extinguish fire, cover with foam)
4	bad access to fire source	insufficient fire fighting, developing fire	on-site emergency operation (extinguish fire, cover with foam), alarm to police and fire brigade
5	fire fighting insufficient	fully developed fire, damage to building, release of toxic fumes	evacuate plant staff, evacuate neighbours, stop traffic to area, remove valuable objects, lead water from fire fighting away from sensitive areas
6	evacuation too slow	harm to people	hospitals, ambulances
7	insufficient collection of water from fire fighting	contamination of recipients	cleaning of contaminated areas
8	fire fighting insufficient	damage to property	build new storage

5. General domain model

5.1 Overall structure

A domain model has been chosen to provide a general framework for representing the different accident and emergency scenarios occurring in the society. A domain can be characterised as a group of activities with allied goals and elements, e.g. transportation, chemical process plants. The starting point for the development of the overall framework has been the *Domain Model Framework* and the *Template for Training and Evaluation* developed during the *MUSTER* project (Multi-User System for Training and Evaluation of environmental emergency management Response, CEC Environment Programme) (Andersen & Andersen 1995).

It is anticipated that an emergency management system will have safety management characteristics similar to other complex systems. Experiences gained from the safety studies indicate a need for a more comprehensive socio-technical approach. This is the reason for developing the description of a domain in a socio-technical frame integrating structural, operational and managerial factors. The objectives of the domain model is:

- to structure the development of a training scenario
- to ensure that the necessary information and documentation is provided, considered and integrated in the training scenario.

The model presented focus on how experience and knowledge gained from risk analysis and incident investigations can be transferred to development of incident and emergency scenarios and thereafter applied in the planning of emergency training scenarios. In the model, only less emphasis is laid on planning, execution and evaluation of training sessions as this task treated in a separate part of the MEMbrain project.

The domain model is of general character and it contains the elements described in the previous chapters. In order to keep the survey of the model and its contents some of the elements have been grouped and combined. The general character of the domain model can imply that some parts of the model will be irrelevant for some domains. The required level of details will vary from domain to domain and there can be a need for a more detailed model on specific topics for specific domains/activities.

The domain model is presented in a tabular form in Table 5-1 "Status", Table 5-2 "Context" and Table 5-3 "Training". The intention is that only the results of the data collection and the analysis are presented in the tables, and therefore the analysis work (hazard identification, development of scenarios etc.) is carried out separately. The structural, operational and managerial factors are integrated and contained in all three categories. The domain model is presented in Figure 5-1.

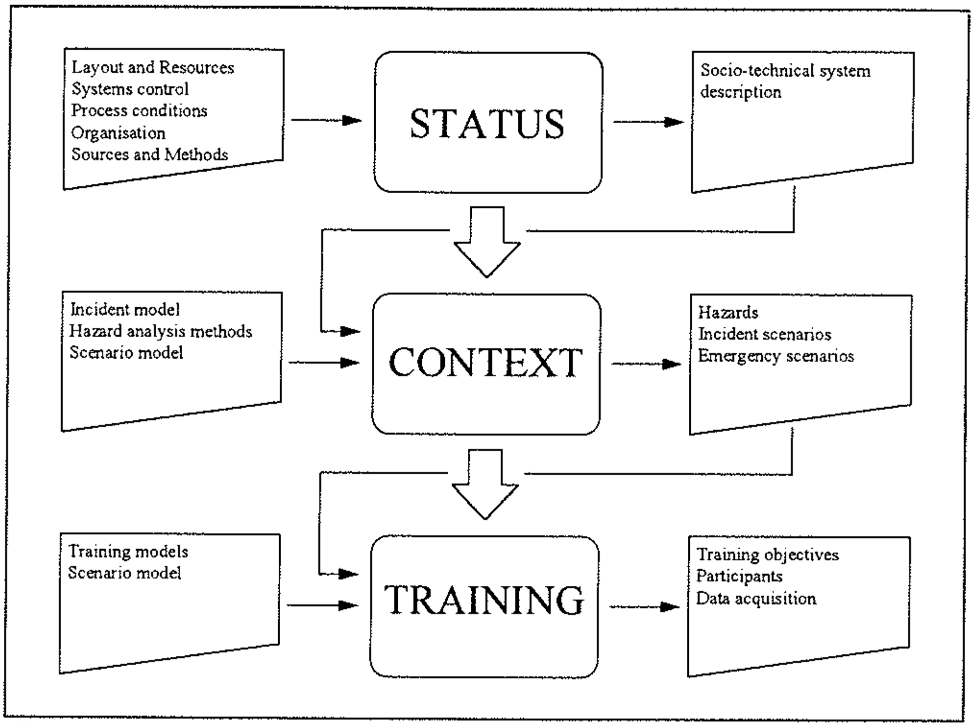

Figure 5-1. Domain model.

The main categories can be described as follows:

- Status: The status contains the list of information and documentation establishing the basis for the development of incident and training scenarios. First of all the analysis object must be agreed and described. Key elements are: territory characteristics, resources, process conditions, systems control, organisation, sources of information and analysis of methods. The objective is to prepare a socio-technical description of the system including structural, operational and managerial factors and to indicate which safety and emergency aspects that will be of interest for the analysis and development work. In the status it is important to ensure that sources of information and analysis methods used are referred and evaluated, as sources of information may reflect particular interests, purposes or perspectives and analysis methods may have different strengths and weaknesses.

- Context: Here the intention is to analyse and assess the safety and emergency characteristics of the domain and to fill in the boxes of the incident and scenario model. Based on the socio-technical system description an overall hazard assessment is carried out by use of risk analysis methods, checklists, key words, lessons learned from accident case stories etc. This forms the basis for describing the incident scenario(s) comprising hazard source(s), confinement(s), UFOE(s) and vulnerable object(s) together with the basic emergency operations the emergency support can establish in order to control or fight the UFOE(s) and to protect the vulnerable object(s). The incident and the emergency scenarios are then evaluated with special reference to the formulation of emergency support where important questions are: which UFOE(s) can be realised and what must be learned to fight/control them ? In the context part key elements are: incident, vulnerable objects, scenario and emergency support.

- Training: Objectives and principles for training are discussed and evaluated. It is considered how to run the training session and how the session is going to be evaluated (data/observations needed and criteria for evaluation of a training session). Key elements are: training objectives, participants, and data acquisition.

The main application of the model is to develop emergency training scenarios for specific domains or activities. Furthermore, the model has been used in the transformation of experiences and knowledge from risk analysis, safety studies and accident investigation into the domain model in order to integrate realistic emergency and accident events (lessons learned) in the planning of training scenarios.

5.2 Status

The status contains the list of information and documentation establishing the basis for the development of incident and training scenarios (Table 5-1). First of all the analysis object must be agreed and described. Key elements are: territory characteristics, resources, process conditions, systems control, organisation, sources of information and analysis of methods. The objective is to prepare a socio-technical description of the system including structural, operational and managerial factors and to indicate which safety and emergency aspects that will be of interest for the analysis and development work. In the status it is important to ensure that sources of information and analysis methods used are referred and evaluated, as sources of information may reflect particular interests, purposes or perspectives and analysis methods may have different strengths and weaknesses.

Territory characteristics

- Area (e.g. urban, industrial, rural): What are the demographic features of the area in which the emergency occurs ? The area can be represented by a map, at a more or less detailed level, showing residences, infrastructure, schools, hospitals etc. It is important to consider the static as well as the dynamic demographically information (for instance, is there in the neighbourhood a football stadium where a large amount of people can be present ?)
- Population density: How many people can be affected by the incident consequences ? People staying in high risk zones (e.g. plant staff) as well as people staying in the vicinity (e.g. passers-by, neighbours at industries or residences) shall be considered.
- Dispersion routes: How and how far from the source can toxic or radioactive substances (gas, fire effluents, smoke aerosols) be dispersed by air (puffs and plumes) in the environment ? How and how far can liquids (e.g. water from fire fighting) be dispersed to soil, subsoil water or marine recipients (lakes, streams, rivers etc.).
- Meteorological and topographical factors: What are the predominant meteorological factors in the area ? E.g. wind direction, wind speed, atmosphere sta-

bility. Which extreme weather conditions are relevant ? What are the geographical and topographical features of the area in which the emergency occurs ? e.g. surface roughness and buildings and obstructions (features with influence on incident propagation or physical constraints in the territory of importance for the emergency management). Who can be affected by the incident consequences ? E.g. topographical conditions, plant layout, activities in the vicinity (e.g. schools, companies), infrastructure.

Table 5-1. Domain model - Status.

STATUS		DOMAIN
TERRITORY CHARAC-TERISTICS	area (e.g. urban, industrial, rural)	
	population density	
	dispersion routes	
	meteorological and topographical factors	
RESOURCES	personnel directly involved in the activity	
	technical configuration	
	amount and number of chemical substances	
	construction materials	
	electrical supply system	
	communication system	
	transport system	
PROCESS CONDITION	energy potential	
	temperature, high/low	
	pressure, high/low	
SYSTEMS CONTROL	automation	
	instrumentation	
	on-line control	
	process control	
	operator supervision	
	safety systems, confinement	
ORGANISATION	work organisation	
	safety organisation	
SOURCES OF INFORMATION	system documentation	
	literature	
	accident descriptions	
	information from organisations/consultants	
	information from authorities	
	validation of information and sources	
ANALYSIS METHODS	structural factors	
	operational factors	
	managerial factors	

Resources

- Personnel directly involved in the activity: Which people can through performance of their job functions and operations become embroiled in or contribute to an emergency ? e.g. plant personnel, crew members, contractors, suppliers, customers. In special cases it might be relevant also to consider sabotage or other unauthorised man-made incidents.

- Technical configuration: The amount of documentation will depend on the complexity of the activity. In general, the basic principles of the technical processes/operations are described: basic units, basic operations, physical changes and chemical reactions, operational storages, utilities to normal and emergency response operations, waste treatment etc. The technical configuration can be supplemented by a map/situation plan/diagram showing the main installations and their location.
- Amount and number of chemical substances: This includes description of dangerous substances and mixtures (e.g. toxic, flammables, explosives, radioactive) handled at the plant/activity/transport. The state, amount, properties, location and logistics of the substances and mixtures should be described.
- Construction materials: In case of fire, explosion or release the construction materials will have a large impact on the development of the incident course. The type, amount, application and location of the construction materials shall be described.
- Electrical supply system: Own supply system at the plant/activity or public supply system and/or standby power apparatus. The important point to identify is the vulnerability of the domain and its activities with respect to power supply failures. Is a standby power apparatus available.
- Communication system: For each unit/function, list the types of communication channels and the type of information exchanged. This shall comprise internal as well as external communication systems.
- Transport system: List the facilities for transportation of people, materials and substances within the activity/domain and the external transport facilities. E.g. pipeline, lorry, truck, container, rail, road etc.

Process condition

- Energy potential: Assess the energy potential of the domain/activity. Are there large amount of flammables or fuel ? High voltage ? How fast can the energy be released ?
- Temperature, high/low: List and locate the functions/units with high or low operation temperatures. List the amount of materials hold at high/low temperatures.
- Pressure, high/low: List and locate the functions/units with high or low operation pressures. List the amount of materials hold at high/low pressures.

Systems control

- Automation: Is the activity manual or automatically controlled and supervised ? For many activities the degree of automation will vary from unit to unit, and it can therefore be necessary to perform an overall assessment of the degree of automation focusing the most important units and functions of the activity/domain.
- Instrumentation: List the instruments installed for the following purposes: alarms (e.g. gas, fire, smoke, radiation), control, registration and recording. Assess the degree of instrumentation focusing the most important units and functions of the activity/domain.

- On-line control: List the degree of on-line control for the different units/functions of the activity: process operations, storage facilities, transport systems etc.
- Process control: What are the main tasks of the control system ? E.g. registration of process parameters, registration of storage conditions, regulation of process parameters, activation protective and preventive measures in case of deviations.
- Operator supervision: Which operators tasks are carried out ? Which functions and processes do the operators register and supervise ? Is the registration carried out as control room supervision or are there regular inspection rounds ?
- Safety systems, confinement: Which safety systems have been installed ? How is the confinement designed ? Confinement can be e.g. passive active barriers, sustained energy, preventive and protective measures.

Organisation

- Work organisation: How is the normal operation work organised ? How is the hierarchical management structure (e.g. operator, operation leader, managing engineer, director). How are the strategic, tactic and operational principles described for work and safety. How are resources are allocated.
- Safety organisation: How is the safety organisation structured ? Are safety issues separated from other areas of responsibility, e.g. is a safety officer appointed. Which auditing and control functions are carried out by the authorities ?

Sources of information

- System documentation: Which kind of information have been used ? E.g. PI diagrams, flow charts, process description, procedures, instructions, emergency plans, maintenance plans, logs of operation data, construction of protective and preventive systems, transportation routes, topographical and demographically information etc.
- Literature: List the open literature referred in the study. E.g. information about chemical substances, component reliability data, structural reliability data, theories on redundancy.
- Accident descriptions: Collect information about accidents/incidents/near misses occurred at the plant/activity/installation or at similar plants/activities/installations.
- Information from organisations/consultants: This can include: specific analysis and investigations (e.g. risk analysis, heath hazards analysis), rescue systems.
- Information from authorities: This can include: external emergency plans, legislative requirements, approvals from the authorities, auditing programmes.
- Validation of information and sources: Is the information up to date ? Is the information available ? Where does the information come from and how was it obtained ? Sources of information may reflect particular interests, purposes or perspectives and analysis methods may have different strengths and weaknesses.

Analysis methods

During the development of the incident and emergency scenario it is important continuously to consider the reasons for carrying out the training. Therefore, the socio-technical description is summarised focusing the most essential structural, operational and managerial factors that lead to the decision to conduct training and evaluation.

- Structural factors: E.g. plant design, plant layout, component reliability, structural reliability, redundancy, containment, alarms, infrastructure.
- Operational factors: E.g. human reliability assessment of procedural tasks, human behaviour in the control of danger, interface, process conditions, process parameters.
- Managerial factors: E.g. fields of responsibilities, qualification of personnel, information channels, safety culture, working discipline, resource allocation, decision-making hierarchy, interaction with other socio-technical systems, public relations.

5.3 Context

Here the intention is to analyse and assess the safety and emergency characteristics of the domain (Table 5-2) and to fill in the boxes of the incident and scenario model. Based on the socio-technical system description an overall hazard assessment is carried out by use of risk analysis methods, checklists, key words, lessons learned from incident case stories etc. This forms the basis for describing the incident scenario(s) comprising hazard source(s), confinement(s), UFOE(s) and vulnerable object(s) together with the basic emergency operations the emergency support can establish in order to control or fight the UFOE(s) and to protect the vulnerable object(s). The incident and the emergency scenarios are then evaluated with special reference to the formulation of emergency support where important questions are: which UFOE(s) can be realised and what must be learned to fight/control them ? In the context part key elements are: incident, vulnerable objects, scenario and emergency support.

Incident

- Hazard source: This contains a listing of the outcome of the hazard identification and hazard evaluation, e.g.: Hazardous substances (flammables, explosives, corrosives, toxic/radioactive substances, reactive chemicals), hazardous conditions (high/low temperature, high/low pressure, reaction/decomposition energy, time aspects) .
- Loss of confinement: Which events can cause loss of confinement ? E.g. containment failure, external damage, weather conditions, operator error, change of pressure.
- Uncontrolled flow of energy: The combination of sufficient energy and inadequate confinements results in uncontrolled flow of energy, e.g. high/low temperature, high/low pressure, reaction energy, missiles.

- Potential exposure: Which types of incidents (and combinations) are relevant, e.g. fire, explosion, release of toxic substances, release of radioactive substances, collision, missile, air crash. What are the primary and subsequent incident consequences ? E.g. harm to humans, harm to environment, contamination damage to materials and property.

Table 5-2. Domain model - Context.

CONTEXT		DOMAIN
INCIDENT	hazard source	
	loss of confinement	
	uncontrolled flow of energy	
	potential exposure	
VULNERABLE OBJECTS	people threatened in high risk zones	
	people that might be affected	
	environmental impacts (recipients)	
	impact on property	
	areas affected by the incident (source distance)	
SCENARIO	incident mechanisms	
	initiating events/upsets	
	external events	
	event sequences (intermediate events)	
	escalation - domino effects	
	duration of event sequences	
	systems response to events/upsets	
	operator/personnel response to events/upsets	
	substances formed during the incident	
EMERGENCY SUPPORT	basic ways of controlling/fighting the UFOE(s)	
	emergency organisations	
	special equipment	
	mitigation systems	
	escape routes	
	alarms	
	inventories	
	communication lines	
	lines of command	
	requirements to personnel qualification	
	contacts to experts	
	possibilities for an efficient emergency control	

Vulnerable objects

- People threatened in high risk zones: Which groups of people might stay in the high risk zones and can they in advance receive information about hazards, alarms and the emergency plans? People in high risk zones can be plant personnel, neighbours, passers-by, passengers.
- People that might be affected: Which groups of people might stay in areas that might be affected by the incident ? This group of people will normally be too large to inform on beforehand. E.g. people staying in the vicinity or in case of nuclear releases people living in neighbour regions and countries.
- Environmental impacts (recipients): Which areas/recipients or flora/fauna might be contaminated and will the threatened areas/recipients be know on

beforehand ? E.g. are the threatened areas/recipients known along a transport route. Important aspects are recipient characteristics (lakes, rivers, streams, agriculture, preserved areas, animals etc.) and dispersion routes (air, water, soil, subsoil water).

- Impact on property: Which types of property can be affected by the incident consequences and which kind of damages are relevant ? E.g. process units, buildings, installations, products, raw materials, infrastructure.
- Areas affected by the incident (source distance): What is the source strength and how far from the source can human beings, environment and property be affected? The assessment shall include different meteorological situations and conditions.

Scenario

- Incident mechanisms: What is the initiating event and which socio-technical factors can contribute to the development of an incident ? List and rank the main events of the incident, e.g. equipment malfunction, containment failure, human error, external event (floods, vandalism), leakage, loss of coolant, structural damage, ignition source, management error.
- Initiating events/upsets: Discuss and define the initiating incident event and determine the incident location. E.g. equipment malfunction, loss of containment, human error, loss of coolant, collision.
- External events: Which external events can have an influence on the emergency operation ? E.g. traffic problems, insufficient knowledge about the activity and the incident, bad weather conditions
- Event sequences (intermediate events): Discuss and determine the intermediate events/upsets. Prepare the event sequences of the incident and emergency scenarios by use of the overall structure presented in Figure 4-3. It is important to consider possible events/upsets and the system and operator responses to the events/upsets. Intermediate events can be divided into to two categories: propagating (e.g. process parameter deviations, containment failures, material releases, loss of utilities, ignition, fire, explosion.) and ameliorative (e.g. safety system response, mitigation system response, contingency operations).
- Escalation - domino effects: Can other activities/plants be involved in the incident course ? List the activities/plants close to the incident location and assess whether or not they can be affected by the incident consequences.
- Duration of event sequences: What are the time conditions for a successful emergency operation ? Assess the duration of each event and of the whole scenario. It is essential to identify the very short (momentary) events. The assessment shall comprise the typical incident course as well as an incident occurring under extreme conditions (e.g. bad weather conditions).
- Systems response to events/upsets: What are the planned system response to events/upsets. E.g. relief valves, vents, dikes, sprinklers, detection, alarms, procedures.
- Operator/personnel response to events/upsets: What are the planned operator response to events/upsets, e.g. report upset and make corrective actions, warning of personnel/passengers/neighbours, use of personnel safety equipment.
- Substances formed during the incident: Which substances can be formed and released during the incident course ? Combustion and decomposition products

from e.g. raw materials, products, construction materials, reaction products from not intended chemical reaction course, substances formed by mixing of wrong chemicals etc.

Emergency support

- Basic ways of fighting/controlling the UFOE(s): How can the UFOE(s) be controlled and how can the damages caused by the UFOE(s) be limited ?
  - ◊ Move vulnerable objects: evacuate plant staff, evacuate neighbours, stop traffic to area, remove valuable objects.
  - ◊ Modify energy: water curtain, extinguish fire.
  - ◊ Redirect flow: lead water from fire fighting away from sensitive areas, collect water from fire fighting (portable spill basins), build interimistic dams.
  - ◊ Control source: extinguish fire, cover leak.
  - ◊ Encapsulate moving energy: cover with foam.
  - ◊ Establish negative source: lead spills to sewer, add chemical agents that react with dangerous substances
- Emergency organisations: Which kinds of competence are needed and which organisations will be involved in the emergency operations. What is the level of preparedness (planned, dedicated, ad hoc) ? Will the emergency operation involve local, regional, national and/or international organisations and authorities ?
- Special equipment: Which kind of special equipment is necessary for the emergency operation ? E.g. emergency treatment of people exposed to toxic chemicals, emergency treatment of people exposed to radioactive materials, fire fighting equipment for special application (e.g. water reactive chemicals), clothing for personnel protections, monitors, shielding equipment, equipment that can operate under high radiation level, ropes, ladders, lights.
- Mitigation systems: Which kind of mitigation systems are necessary for the emergency operation ? E.g. collection of water from fire fighting.
- Escape routes: Are the escape routes well described in the emergency plans or are they going to be established during the emergency operation ? For example, for fixed installations the escape routes will normally be described in the internal contingency plan, but for transport activities the escape routes are more difficult to describe on beforehand.
- Alarms: Which kind of alarms are installed ? E.g. fire, smoke, gas, radiation. Who is warned? E.g. warning systems at: subunit level, company/activity level, region level, national level.
- Inventories: Which kind of inventories must be available to the leader of the emergency operation, e.g. plant layout, substances and materials at the plant/activity, number of people employed, location of workplaces, number of people on duty, head on duty.
- Communication lines: How is the communication and information lines organised ?
- Lines of command: Who is responsible for distribution of information ? E.g. contacts to leader of the emergency operation, contact to head of duty, contact to hospitals, contact between police and fire brigade or other actors.
- Requirements to personnel qualification: Are specific qualification needed for the personnel participating in the emergency operation ? E.g. knowledge about

handling chemical substances, knowledge about radiation and contamination, knowledge about personnel protection, knowledge about human behaviour in hazardous situations.

- Contacts to experts: Is contact to experts and specialists needed during the emergency operation ? E.g. chemists, nuclear reactor engineers, health physicists, doctors, biologists, psychologists.
- Possibilities for an efficient emergency control: What are the possibilities for rescuing the people threatened in the high risk zones ? What are the possibilities to avoid damage to environment and property ? What are the conditions for avoiding incident escalation ?

5.4 Training

Objectives and principles for training are discussed and evaluated. It is considered how to run the training session and how the is session going to be evaluated (Table 5-3). Key elements are: training objectives, participants, and data acquisition.

Training objectives

- Time aspects for on-site operations: How fast will the incident course develop and are there critical events demanding a fast emergency operation. E.g. fast detection of a material release (a fast operation can be necessary to reduce the amount of materials released or to establish shielding equipment), early warning, fast establishment of an on-site emergency operation.
- Priority of decisions and actions: Consider the dynamic behaviour of the incident course. What are the critical actions ? E.g. evacuate people, save lives, protect environment, protect property.
- Critical conditions: Which critical conditions must the emergency personnel be aware of ? E.g. materials and substances involved, amount of materials and substances, high/low temperatures, high/low pressures, domino effects, weather conditions, traffic problems.
- Constraints on access to incident location: How are the possibilities for the emergency personnel to reach the incident location ? For fixed installations are the emergency situation normally taken into account in the plant layout. What concerns transportation incidents it will not be possible on beforehand to predict the incident location.
- Early warning of people: Which organisation is responsible for warning of people staying in high risk zones ? E.g.: police, local authorities, local emergency organisations
- Evacuation (transport of injured persons): Is a fast evacuation necessary ? How many people are going to be evacuated ? What are the main evacuation operations ? E.g. evacuation of people in high risk zones, transportation of injuries to hospital, crowd movement, instructions concerning safety measures.
- Measures for environmental protection: Which kind of measures and knowledge must be available for the environmental protection ? E.g. knowledge

about chemical substances, knowledge about dispersion routes, knowledge about meteorological conditions.

- Operations by internal emergency organisation: Which operations are carried out by the internal emergency organisation - if possible rank the operations with respect to importance for a successful emergency operation. E.g. early detection of an incident, fast call for an emergency, first aid, mitigation measures, early warning of people staying in high risk zones.
- Operations by external emergency organisations: Which operations are carried out by the internal emergency organisation - if possible rank the operations with respect to importance for a successful emergency operation. E.g. evacuation, mitigation measures, information, communication, controlling priorities of emergency tasks.
- Fields of responsibilities: Who is responsible for the emergency operation ? (e.g. for fixed installations the head of the fire brigade is normally head of the emergency operation).What are the fields of responsibilities and will they change during the emergency operation ? E.g. primary emergency operation by internal emergency organisation, transferring the responsibility from the internal to the external organisation, establishment of emergency control centre.
- Communication with the public: Who will be responsible for the communication with the public and which kind of information must be available ? Who are going to be informed at the first time and which kind of information must be available ? E.g. information to relatives, neighbours, authorities, information about injuries and damage to environment.
- Co-operation between organisations: Which organisations will be involved in the emergency operation ? E.g. fire brigade, police, plant staff, hospital, ambulance service and authorities (local, regional, national). Which organisations will have a close co-operation during the emergency operation ? E.g. between internal and external emergency organisations, between the fire brigade and the police.

Table 5-3. Domain model - Training.

TRAINING		DOMAIN
TRAINING OBJECTIVES	critical time aspects for on-site operations	
	priority of decisions and actions	
	critical conditions	
	constraints on access to incident location	
	early warning of people	
	evacuation (transport of injured persons)	
	measures for environmental protection	
	operations by internal emergency organisation	
	operations by external emergency organisations	
	fields of responsibilities	
	communication with the public	
	co-operation between organisations	
PARTICIPANTS	trainees	
	supervisors	
	evaluators	
DATA ACQUISITION	logging	
	observations	

Participants

- Trainees: Who is to be trained and evaluated ? Trainees may occupy different ranks in their organisation. Trainees may be affiliated to the same or different agencies and their work location during an emergency may be the same or different. E.g. safety officer, safety managers, safety engineers, key decision makers.
- Supervisors: Who prepares, supervises and is responsible for the session ? Supervisors may adopt different roles during different phases of a session and these roles may require different amounts of interaction with trainees, e.g. they may instruct/guide/facilitate/observe trainees. Supervisors can be internal or external training experts.
- Evaluators: Who shall evaluate the targets and the results of the session ? Evaluators may have different educational backgrounds and work experience. E.g. representatives from the company, the authorities, the emergency organisations

Data acquisition

- Logging: What data/records of the session or data/records about the session are logged ? Records may indicate the behaviour of the trainees and can be e.g. computer logs, video/audio tape recordings.
- Observations: Which kind of session observations are taken ? Observations may be subjective notes taken by the supervisors indicating the behaviour of the participants in the control of danger, e.g. stress factors.

6. Specific domains

6.1 Transformation of experiences from risk analysis and accident investigation

To collect accident knowledge for later transfer to training scenarios, the first step was to sketch a set of domains for generic accident descriptions which cover the majority of accidents occurring in the society. As the second step, these generic accident descriptions were elaborated by use of knowledge and experience from risk analysis together with information from 25 accident cases. Experience from the case work has lead to several minor adjustments of the schemes, and a more general result of the case work at this point is that it has formed the background for making the accident model described in chapter 3. The model development and the investigation of cases has been carried out as an iterative process as indicated in Figure 6-1.

Adequate tools will be needed for structuring and governing the transfer of accident knowledge between the sphere of risk analysis on one side, and the scenario-and-training set-up on the other. In the delivery end, where accident knowledge is fed into training systems, it must be expressed in forms, that are optimal in terms of data volume and in terms of accessibility for the training process: the sum of accident knowledge must be compressed, but structured in such a way, that it can be used both for construction of training scenarios and for implementing realistic reactions and scenario adjustments during the training session.

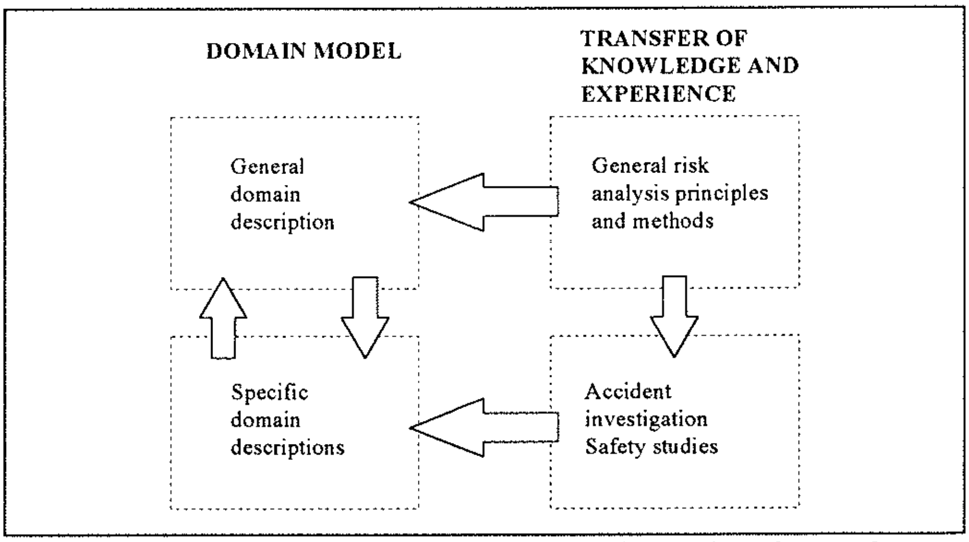

Figure 6-1. Transfer of knowledge and experience from risk analysis and accident investigation.

In the development of the domain scheme (see chapter 5) a requirement was that all accident information could be handled and that the scheme would facilitate comparisons to identify the significant characteristics between each domain.

Table 6-1 presents the 10 generic domains together with the 25 selected accident cases. The specific domain descriptions together with the analysis of the accident case stories can be found in the enclosure A-J.

Table 6-1 Specific domains and accident case stories

DOMAIN	ACCIDENTS
Process plant	Seveso - release of dioxin (1976, Italy) Bhopal - release of methyl isocyanate (1984, India) Griesheim - release of reaction mixture (1993, Germany)
Storage	Jonova - ammonia tank failure (1989, Lithuania) San Juanico - gas explosion (1984, Mexico) Basle - warehouse fire (1986, Switzerland)
Power plant - nuclear	Athens - fire at nuclear plant (1975, Alabama, USA) Chernobyl - accident at reactor (1986, Ukraine, Russia) Three Mile Island - accident at reactor (1979, Penn., USA) Leningrad - fuel channel rupture (1992, Russia)
Energy distribution (reservoirs, pipelines, storages)	North Sea - explosion off-shore platform (1988, England) Gothenburg - propane pipeline explosion (1981, Sweden) Bashkir - gas pipeline rupture and explosion (1989, USSR)
Marine transport (goods)	Prince William Sound - oil release (1989, Alaska, USA) Grays Harbour - oil release (1988, Washington State, USA)
Marine transport (people)	Skagerrak - fire on ferry (1990, Denmark) Zeebrugge - capsize (1987, Belgium)
Aviation	Washington Nat. Airp. - collision with bridge (1982, USA) Leicestershire - air crash on motorway (1989, England)
Transport by road	Möbling - release of phenol (1982, Austria) Los Alfaques - campsite disaster (1978, Spain)
Transport by rail	King's Cross - fire (1987, London, England) Næstved - release of acrylonitrile (1992, Denmark)
Natural disasters	Awaji Island - earthquake (1995, Japan) Leeaward Island - hurricane (1989, Caribbean)

6.2 Applying the general framework on specific domains

As mentioned one of the basic ideas of the domain model and scheme was to facilitate comparisons between generic domains and to identify the significant characteristics between them. In this section characteristics for each generic domain are summarised where emphasis is laid on the characteristics most relevant from an emergency point of view. The characteristics are described following the structure of the domain model, i.e. status, context and training. The detailed descriptions of each domain can be found in enclosures.

Process plant

- Status: Process plants are fixed installations normally located in urban or industrial areas. The population density (e.g. residences, enterprises, passers-by) can be relatively high. The plant consists of process units, storages, utility systems, laboratories and offices. The number of chemical substances are

Large quantities of flammable or reactive chemicals can be present and these are often handled at high/low temperatures and pressures. Several operations (manual or automated) are carried out. The process operation, control and alarm systems are often designed with a high degree of automation and sprinklers or other protective measures are installed. The most essential confinement is the storage building, containers, vessels etc. The organisation of work and safety issues can be found in the plant documentation.

- Context: The hazard source is hazardous chemicals (e.g. flammables, reactive, radioactive) or hazardous process conditions (high/low temperature, high/low pressure). The UFOE can be release of reaction energy, missiles, shock waves, radiative heatflux etc. Loss of confinement can be containment failure, leakages, change of pressure etc. Plant personnel, neighbours and passers-by can be affected by the accident and many of these can receive information in advance about hazards, alarms and how to behave in case of an emergency. The accident can occur in very short time, less than 10 minutes from the initiating event till the UFOE is released and escalation is possible from one plant unit to another. Primary victims can be difficult to rescue. Many different chemical substances can be released (fire or reaction products) and the accident may cause harm to the environment. The threatened recipients will often be known in advance by the plant personnel and the competent authorities. For process plants emergency plans are often prepared describing the responsibilities and duties for the internal and external emergency organisations.
- Training: A fast emergency operation is normally needed as the accident course may develop fast and a fast evacuation and warning of people is necessary. The primary emergency operations are carried out by the internal emergency organisation and good communication with external organisations is significant for a successful emergency operation. Critical factors during the emergency operation are knowledge about the chemical substances and their properties, knowledge about first aid, knowledge about dispersion of chemicals to environment, available transportable basins for collection of water from fire fighting, weather conditions etc.

Storage

- Status: Storages are fixed installations normally located in urban or industrial areas. The population density (e.g. residences, enterprises, passers-by) can be relatively high. The plant consists of facilities for transferring substances (e.g. trucks, vessels, containers, pipelines) utility systems and offices. The number of chemical substances are normally few but in very large amount and well-known by the plant staff and the competent authorities. Large quantities of flammable or reactive chemicals can be present and these are often handled at high/low temperatures and pressures. The operation, control and alarm systems are often designed with a low degree of automation. Sprinklers or other protective measures are often installed. The most essential confinement is the storage building, containers, vessels etc. The organisation of work and safety issues can be found in the plant documentation.
- Context: The hazard source is the very large quantities of hazardous chemicals (e.g. flammables, reactive, radioactive) which can be stored at high/low pressure or high/low temperature. The UFOE can be release of decomposition

energy, missiles, shock waves, BLEVE, radiative heatflux etc. Loss of confinement can be containment failure, leakages, ruptures etc. Plant personnel, neighbours and passers-by can be affected by the accident and many of these can receive information in advance about hazards, alarms and how to behave in case of an emergency. The accident can occur in very short time, less than 10 minutes from the initiating event till the UFOE is released and escalation is possible from one plant unit to another. Primary victims can be difficult to rescue. Many different chemical substances can be released (e.g. decomposition and fire products) and the accident may cause harm to the environment. The threatened recipients will often be known in advance by the plant personnel and the competent authorities. For storages emergency plans are often prepared describing the responsibilities and duties for the internal and external emergency organisations.

- Training: A fast emergency operation is normally needed as large quantities of chemical substances may be released fast and a fast evacuation and warning of people are necessary. The primary emergency operations are carried out by the internal emergency organisation and good communication with external organisations is significant for a successful emergency operation. Often very large amount of chemicals are involved and therefore emergency organisations from different regions and municipalities can be involved. Critical factors during the emergency operation are knowledge about the chemical substances and their properties, knowledge about first aid, knowledge about dispersion of chemicals to environment, available transportable basins for collection of water from fire fighting, weather conditions etc.

Power plant - nuclear

- Status: Nuclear power plants are fixed installations normally located in industrial areas. The population density can be relatively high (e.g. plant personnel, neighbours, enterprises). The plant consists of reactors, generators, storages, utility systems and offices. The number of substances are normally few and large quantities of radioactive fuel are present. The process operation, control and alarm systems are often designed with a high degree of automation. The containment around the reactor building is the most essential confinement. The organisation of work and safety issues can be found in the plant documentation. The nuclear power plant industry has a long tradition for collection and analysis of operational reliability data.
- Context: The hazard source is large quantities of radioactive substances combined with a high reaction energy in the reactor core. The UFOE will be release of nuclear energy, thermal explosion etc. Loss of confinement can be damage to containment, rupture of process equipment etc. Plant personnel, neighbours and passers-by are the primary victims but the accident can affect large areas (regions, countries). The exposure may cause long-term or chronic effects on human beings and the environment. The accident can occur in short time, typically hours from the initiating event till the UFOE is released. The accident may cause harm to the environment at long distances from the source (harm to animals, contamination of soil, vegetables etc.). Therefore emergency organisations can be involved at local, regional, national and international level.

- Training: A fast emergency operation is normally needed as the accident course may develop fast and a fast evacuation and warning of people are necessary in large areas. The primary emergency operations are carried out by the internal emergency organisation and good communication with external organisations is significant for a successful emergency operation. A large amount of radioactive substances can be released and dispersed by the wind and therefore emergency organisations from different regions and even countries can be involved. Critical factors during the emergency operation are knowledge about the radioactive substances and their properties, knowledge about first aid, knowledge about dispersion over long distances, wind and weather conditions etc.

Energy distribution (reservoirs, pipelines, storages)

- Status: Energy distribution systems can be situated offshore or onshore in urban, industrial or rural areas, e.g. passage of pipelines through different regions. Consequently, the population density can vary from low to high, e.g. at offshore installations 200-300 people can stay in a relatively small area. The distribution system consists of pipelines, utility systems, storages and control measures. Normally only one product/substance/chemical is present in the distribution system and large amount of flammable/explosive substances can be present. There will often be a high degree of automation and instrumentation what concerns the transfer, control and supervision operations. Central confinements are the process equipment (pipelines, containers). The organisation of work and safety issues can be found in the documentation for the installation.
- Context: The hazard source is the large quantity of flammable and explosive which often is pressurised. The UFOE will be a fire/explosion followed by violent heat generation, blast and missiles. Loss of confinement can be damage to containment, leakage or deviations in process parameters, e.g. pressure change. Plant personnel, neighbours and passers-by are the primary victims. At offshore installations many people will stay in a relatively small area which can make escape from the accident location difficult. The accident can occur in very short time, less than 10 minutes from the initiating event till the UFOE is released and escalation is possible from one part of the installation to another. The threatened recipients will often be known by the personnel and the competent authorities. For the energy distribution installations emergency plans are often prepared describing the responsibilities and duties for the internal and external emergency organisations.
- Training: A fast emergency operation is normally needed as the accident course may develop fast and a fast evacuation and warning of people are necessary. The primary emergency operations are carried out by the internal emergency organisation and good communication with external organisations is significant for a successful emergency operation. At offshore installations people can stay close to the accident location and it is important for the personnel to reach a safe location very fast. Often very large amount of highly flammable fuels are involved and therefore emergency organisations from different regions and municipalities can be involved. Critical factors during the emergency operation are e.g. knowledge about the chemical substances and their properties, knowledge about first aid.

Marine transport (goods)

- Status: The transports will be carried out by tankers (e.g. oil, chemicals) or carriers (gas) involving operations in harbours, restricted waters, coastal waters and at the sea. The only people involved directly in the transport are the crew members and they are often supported by onshore navigation centres. During the transport an automatic pilot can be activated and the route and direction are controlled by radar systems. The number of chemicals involved will depend on the cargo varying from tankers with one substance (e.g. oil) to combination carriers transporting several substances. The most essential confinement is the tanker hull. The organisation of work and safety on board can be found in the tanker/carrier documentation.
- Context: The hazard source is the large quantity of chemicals/oil which can be released to the marine environment. Loss of confinement can be damage to tanker hull or capsizing. Crew members are the primary victims. A large release of oil/chemicals can cause damage to sensitive marine or coastal recipients (birds, fishes, mammals etc.) which also can affect commercial interests (e.g. fishing, tourism) and the people living in the area. The source distance can be very long (500-1000 km) and large areas and coastal lines can be polluted. The initiating event and the release can occur in short time but it can take hours or days before a release reaches coastal lines. In case of an emergency the captain is responsible for making a report to the authorities responsible for the area, e.g. the coast guards.
- Training: There can be a relatively long period of time for supervising the release and preparation of the emergency actions. It might be necessary to evacuate the crew in a very short time. The clean-up activities may involve thousands of people from different organisations which requires a strong coordination. The currents and the weather conditions can have a significant influence on the dispersion of the release and the emergency operations. Critical factors during the emergency operations can be collection/skimming of released oil/chemicals and forecasts concerning currents and wind.

Marine transport (people)

- Status: The marine traffic with ferries and ships involves operations in harbours, inland waterways and at the sea. The number of people on board (passengers and crew) can be very high, 1000 or more. Typically a ship or ferry consists of car deck, accommodation deck(s), lounges (bars, restaurants, shops etc.), bridge deck, engine room, fuel tanks and utility systems. Important safety systems and confinements are the hull of ship, bow doors, alarm, fire fighting system, lifeboat. The organisation of work and safety on board can be found in the ship documentation.
- Context: The hazard source can be either fire and smoke on board or entering of water. Loss of confinement can be leak in hull/bow doors or a fire. Solely the crew members and the passengers will be affected The accident can occur in short time ½-1 hour. Many people will stay in a relatively small area which can make escape from the accident location difficult. Escape routes are normally described in the emergency plans but they can be difficult to use in case of an emergency due to smoke/fire/capsize. On board the captain is the responsible leader of the emergency operations.

- Training: A fast evacuation of the passengers and crew is needed. It is important to get people from the cabins/lounges/car decks to the lifeboats. The accident can escalate very fast. Several hundreds of people can be on board and the rescue operations may involve emergency organisations (e.g. air forces and navies) from many countries which requires a strong co-ordination. A control centre for the emergency operations and public communications is often established. Critical factors during the emergency operations are weather conditions (wind, temperature, rain, snow etc.) and weather forecasts.

Aviation

- Status: The airborne traffic crosses urban, industrial and rural areas and consequently the population density can vary from very low to very high. The number of people on board (passengers and crew) can be relatively high, about 200 or more. The only people involved directly in the transport are the crew members and they are often supported by the airport and tower team personnel. Large amount (5-10 tonnes) of highly flammable jet fuel can be present (decreasing from departure to arrival). The most important safety system is the flight engine.
- Context: The hazard source is loss of mechanical energy, air crash and fire. The primary victims will be the crew and the passengers. Passers-by or people staying in the target area can be affected. The accident may develop very fast from the failure is realised until the air crash. The primary victims can be difficult to rescue.
- Training: The development of the accident course may be very fast and a large number of survivors may need a very fast medical treatment. Several emergency organisations will be involved (hospitals, ambulance service, police etc.) which requires a strong co-ordination. The air crash may occur in an impassable area (e.g. mountains) which can complicate the rescue operations significant. Critical factors during the emergency operations are weather conditions (wind, temperature, rain, snow etc.).

Transport by road

- Status: The transport by road will pass through urban, industrial and rural areas and consequently the population density can vary from very low to very high. Constricted routes might be prescribed for transport of dangerous goods through urban areas. A transport by road will typically consist of traction unit, tanker and cargo materials (20-40 tonnes in containers, drums, sacks, etc.) and more than one chemical substance can be transported by the same cargo. Often only the driver is directly involved in the transport. The safety systems are the tanker and/or the packaging materials.
- Context: The hazard source is the dangerous goods in the cargo (flammable, toxic substances etc.) Loss of confinement can be containment failure (structural damage to tanker, container, drum, sack etc.). The primary victims are the lorry driver and the people staying close to the accident location. The UFOE can be release of chemicals, missiles, radiative heatflux etc. The accident may develop very fast from the initiating failure is realised until the substances are released.

- Training: The accident can escalate within few minutes and a fast emergency operation is needed. Transport accidents will often occur in public areas and it is important to prevent that passers-by are getting access to the accident location. The car collision may occur in an impassable area (e.g. river banks, slopes) which can complicate the emergency operations significant. Critical factors during the emergency operations are weather conditions (wind, temperature, rain, snow etc.).

Transport by rail

- Status: The transport by rail will pass through urban, industrial and rural areas and consequently the population density can vary from very low to very high. The persons directly involved are the railway staff (train and station) and the passengers (train and station). With respect to transport of goods by rail more than one chemical substance/mixture can be transported by the same rail transport. The transport is supervised by the engine driver and the railway operating divisions. Important safety systems are the signal systems and the construction of the tank wagons.
- Context: The hazard source is the dangerous goods in the cargo (flammable, toxic substances etc.) or train collision. Loss of confinement can be containment failure (structural damage to tanker, container, drum, sack etc.). The primary victims are the railway staff and the passengers. The UFOE can be release of chemicals, missiles, radiative heatflux etc. The accident may develop very fast from the initiating failure is realised until the substances are released. At railway stations escape routes are normally designated.
- Training: The accident can escalate within few minutes and a fast emergency operation is needed. Railway accidents will often occur in public areas and it is important to prevent that passers-by are getting access to the accident location. The train collision may occur in an impassable area (e.g. bridges, tunnels) which can complicate the emergency operations significant. Critical factors during the emergency operations are weather conditions (wind, temperature, rain, snow etc.).

Natural disasters

- Status: Natural disasters can occur everywhere and consequently the population density can vary from very low to very high. The forces of nature released during the disaster can be very high. The emergency preparedness will often involve organisations at local, regional, national and international level. Central elements in the disaster preparedness are theories on natural disasters and forecasting.
- Context: The hazard source is nature, i.e. the earth's surface with its climate, vulcanic activities etc. The UFOE can be hurricanes, earthquakes, avalanches etc. A natural disaster can cause a huge number of fatalities and serious injuries. Supply systems (clean water, electricity, gas etc.), buildings and infra structure will often be damaged which will complicate the emergency operations significant. The disaster will often occur fast but the emergency protective actions (evacuation, transport of injuries, fire fighting, dam construction etc.) and the clean-up will often be necessary for several days/weeks. Some

natural disasters, e.g. hurricanes, can be forecasted several days before inhabited areas are affected and disaster preparedness actions can be done to reduce the consequences of the disaster.

- Training: Fast emergency operations can be needed at several locations at the same time. It may be necessary to evacuate a huge number of people from the target area. It is important to obtain a clear identification of the response needs in order to make a priority of emergency actions. A natural disaster may initiate new accidents, e.g. collapse of residential dwellings, which will increase the need for emergency actions. Several emergency organisations from different municipalities and regions will be involved (hospitals, ambulance service, fire brigades, civil defence, police etc.) which requires a strong co-ordination. Critical factors during the emergency operations are weather conditions.

7. Conclusion and discussion

7.1 Overall frame for representing emergency scenarios

In the training of emergency managers accident processes like fire, radiation and structural collapse are referred to along with event sequences, which in combination create the space for emergency operations. An accident scenario can be copied from an actual accident case, it can be a reflection of reference scenarios in the contingency plans or it can be a postulated scenario made specifically for training of a critical emergency action. During the development work of the overall frame for representing emergency scenarios four requirements have been considered:

- the output should be usable for emergency managers and instructors
- the accident information package should be in a form suited for computer system actions
- the frame had to be practical for collection and presentation of accident experience
- clear overviews of several accidents using one and the same frame should facilitate formulation of significant traits distinguishing the specific accident types.

The two last requirements have been fulfilled within the present work, but whether the first two are approached in a suitable way has not been possible to evaluate in the period.

The main steps in this project have been:

- defining a set of accident types classified in domains
- developing an accident model and a model for emergency measures
- developing an overall frame for describing domains
- extracting accident knowledge from selected cases.

Knowledge extracted from accidents should be representative, but it must also be structured in a pattern suitable for training purposes. Ideally, the representation should cover both the accident archetypes and the elements of system behaviour that are additional prerequisites for interpreting and controlling accident situations. For each domain or class of accidents a proper "case" could be conceived as a weighted average of information drawn from relevant and nearly relevant cases together with imagined accidents, everything transformed and corrected to fit the domain definition. To be fully representative, such knowledge has to be both true to the risk objects and significant to the trained subjects. The modification and merging into archetypes has not been made, but focus on the typical was exercised in choosing the cases to be included.

An accident scenario is one way of modelling a threat: experimenting on our images of the physical world in order to derive and describe effects on people and environment may produce a possible development in the physical parameters, giving as a result either a hypothetical accident or a suggestion of how a real accident might have developed and produced the already known consequences. Buried in any accident scenario are assumptions on the physical processes, on state values (are the conditions like we believe them to be ?), on human behaviour etc. and these assumptions contribute their uncertainties to the inaccuracy of a scenario as a representation of a particular accident. But despite these errors, the accident scenario may still contribute a valuable message, adequate both for risk judgements and for educating emergency managers.

Another way of modelling the threat is the accident model, that describes in a universal picture, what happens during an accident, the UFOE model is such a model, trying in a most concentrated manner to picture all sorts of accidents. It was made for the purpose of finding a suitable main structure for accident knowledge where all accident domains could be included, and the emphasis was put on the core of the accident with a view to the interests of emergency managers. Things like right and wrong actions, goals, plans, system states etc. are left out, but these are crucial terms for accident prevention and investigation, nevertheless a general formula for an accident can be useful also in these areas. For emergency purposes the basic ways of controlling/fighting UFOE's was proposed, which connects the central UFOE model to the emergency operations, in particularly concentrating on the physical accident process and deriving objectives and actions from that. Alternatively the accident model can be treated with proper decision models to look for correlations and transformation routes between accident physics and emergency manager.

The accident scenario model and the UFOE concept have been found to be a usable way to describe the majority of the specific domains. With some categories of accidents, e.g. air crash and capsizing, the accident model is not straightforward to use. For these types of emergency scenarios it is easy to identify the hazard source and the vulnerable objects but it is not quite clear how to interpret and specify the loss of containment and the uncontrolled flow of energy.

The domain model is a practical frame for generation of accident and emergency scenarios - a method to ensure that the relevant issues are considered. Filling in the frame and providing the necessary information requires the application of analysis techniques and methodologies from different fields, e.g. hazard identification, risk analysis, dispersion calculations, evaluation of health effects, evaluation of environmental effects. Recommendations concerning these analysis techniques and methodologies have not been integrated in the domain model and the selection of appropriate analysis techniques and methodologies has to be considered during the development of each specific emergency and training scenario.

7.2 Accident investigation

The investigation featured ten specific domains: process plant, storage, nuclear power plant, energy distribution, marine transport of goods, marine transport of people, aviation, transport by road, transport by rail and natural disasters. Totally 25 accident cases were consulted and information was extracted for filling into the schematic representations with two to four cases pr. specific domain. The material illustrates some characteristic differences between accident domains, but the sample is by no means conclusive about such differences.

Furthermore, the division of "all accidents" into ten classes is a rather arbitrary choice which to some extent reflects an emphasis on technology-driven accidents as opposed to natural accidents. This division is not fair towards the consequences and costs of natural disasters compared to for instance accidents caused by transportation of dangerous goods.

The storage of large amounts of flammable or chemically active substances lays the groundwork for potential disasters, especially because long-range accident consequences may threaten larger communities and at the same time delay emergency operations and evacuation. For storage of one or a few different substances like the typical NH_3 - or LPG-storage, the real emergency challenge is with the rapid development of long range consequences from an accident. For industrial plants and for the transport of dangerous substances, emergency operations may be delayed and made difficult because of the need for identifying involved and developed substances and choosing adequate measures. For the domains airplane, ship/ferry and natural disaster it is a depressing fact, that hundreds of human lives are at stake, and complete rescue in such disasters may be physically impossible.

7.3 Generation of emergency scenarios

An essential question related to the development of emergency scenarios is whether or not a universal ordering of information in accident reports is feasible, and if so being the case: how does it relate to the way emergency managers and instructors conceive an accident ? There are obvious differences in the needs of accident investigators and emergency managers as for instance the focus with the first group on causation and possible responsibilities for missing or wrong actions, an the focus with the emergency managers on planning, means/tools and dynamic parameters.

The preparation of emergency scenarios includes considering provision of the necessary data and the level of detail. The comprehensive store of accident experience can be imagined as some sort of data bank with case descriptions in a convenient structure giving access to specific data using a proper search profile. But access to such data is not sufficient for scenario generation because the preparation of emergency scenarios also requires knowledge for simulation of emergency event sequences, and a scenario generator, that contained and could use such knowledge is steps ahead of present exercise practice. Furthermore, the data bank will only contain historical data which of course not will be sufficient to cover all future emergency situations.

Training scenarios are composed in different ways depending on the purpose and motive of the particular exercise. Very often there will be components from so called "design basis accident" together with elements from actual emergency cases which all together is tied up with the creative imagination of instructors and exercise planners. It would be a clear improvement if an accident and emergency data bank could be constructed containing consequence calculations and practical representations of accident states, consequences and emergency actions. An even more ambitious idea would be, if a scenario generator could be developed, that could support the generation of accident and emergency simulations with a built in correspondence between physical accident event sequences and the operational and organisational measurements, observations and registrations.

In the present investigation of accidents it has not been possible to prepare a generic description of an accident and emergency scenario which will cover all the analysed domains. A few general observations can be made which might be of importance for the development and preparation of emergency training scenarios:

- For each specific domain experiences from more than one accident have been extracted showing significant differences what concerns accident course, success of emergency operations, exposure of vulnerable objects, accident consequences etc. It is important in the development of emergency training scenarios to be inspired by accident case stories in order to ensure that the training scenario contains realistic events and situations.
- In several of the accidents insufficient management was one of the essential causal factors leading to the initiation of an accident course. In some cases the insufficient management together with the diverted effects on the system did also have a negative influence on the emergency operations. This could mean that the history of an accident does have an impact on the success of the emergency operations and that the whole accident scenario shall be considered when emergency training scenarios are developed.

7.4 Accidents and planning

An emergency manager mostly faces a host of practical problems, where delays, missing information and operational problems consume most attention, but for higher level - strategic - decisions one needs to know more about the accident, than message contents. For these decisions and in planning for more than some minutes ahead one must look behind the signals and events, one must construct some picture (or model) of the accident, so that one can figure possible future states of the accident system. On a simple scale it may be just being able to diagnose a fire as either "developing" or "decaying", in general it must deal also with possible new events resulting from the accident state and the emergency actions. Several chemical and physical processes can be involved and a large repertoire of accident mechanisms can be activated, which no emergency manager can be familiar with, but to overview masses of information from observations and to direct planning efforts the simple models with uncontrolled flow of energy may prove useful. Obviously this may be completely wrong, perhaps the universal concept of flowing energy is too much of an academic construct, it has already been stated above, that objects (like an airplane) dropping from the sky are not easily interpreted as a flow of energy, the same way as a moving cloud of ammonia or the heat radiation from a fire. The two models have been practical as an input/support in the frame development, and they may prove useful in other areas like the basic risk analysis function of generating key scenarios for risk specification and calculations. It may also be used as a background for accident prevention, where it emphasises the physical characteristics in a sort of source-agent-harm space, which is where the accident is eventually caused or avoided. Accident prevention has to be exercised at all states from design and construction, maintenance, planning and operation etc. to education and monitoring, and human actions are influenced by both knowledge, experience and sensations but in the end prevention is a matter of physically controlling objects and energy flows.

In risk analysis and related judgements about safety one makes use of reference accidents, that are meant to represent, what might happen if things go wrong. Such accident scenarios direct the analysis and greatly influences our image of the risk object, it may therefore be questioned afterwards, if the scenarios chosen make a representative sample, i.e. could quite different events and phenomena contribute significant risk elements? Is the scaling optimistic or pessimistic enough ? In domains with long accident histories like building fires and capsizing ships there will be strong statistic evidence on the prevailing accident processes, one can therefore conceive the representative "fire" or "capsize" as a core accident type with room for other dimensions, dynamics and causation. On the other side there are quite new domains like the nuclear power plants, the computer society with its internet, data registers etc. and the industrialised food sector, where one must obviously add theoretical accident scenarios as long as the actual accident experience cannot be taken as representative. If the safety work in a certain domain really succeeds to a such extent, that serious accidents get very scarce, then we can't represent accident potential without relying on theoretical scenarios.

Public planners at local, regional and national level deal with risk information, i.e. certain facts about possible accidents and incidents with negative consequences for society, that may result from instabilities, errors or external impacts at the different activities in their area of responsibility. The planning work calls for simple accident models to support decisions on plant layout, safety zones and other restrictions necessary for the co-existence of industries and other activities in the society. Also, in the public planning of land use one needs accident knowledge to support decisions on plant layout, safety zones and other restrictions.

A common issue for emergency managers and land use planners is to provide and apply a large amount of information and knowledge about accident risks. In order to support their work the accident information and knowledge shall be available in an operational form. Emergency managers and developers of contingency plans need adequate representations of the potential accidents, emphasising both the consequences, the anatomy of the accident and the controllability. Land use planners must face all sorts of potential accidents, that may happen at fixed installations, on traffic lines, or just anywhere, like air crashes, natural disasters and certain pollution cases. The structuring of the domain descriptions together with the accident and scenario models can be used as a general coding scheme for extracting and representing accident knowledge, thus partly overcoming the problem of "planning for the most recent accident".

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APPENDIX A

Process plant

Accidents

Seveso - release of dioxin (1976, Italy)
Bhopal - release of methyl isocyanate (1984, India)
Griesheim - release of reaction mixture (1993, Germany)

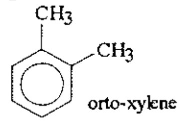
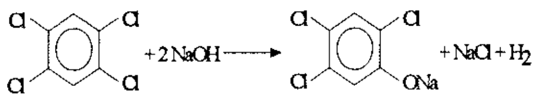
STATUS (I)		PROCESS PLANT
TERRITORY	area (e.g. urban, industrial, rural)	urban or industrial
CHARACTERISTICS	population density	high ⇨ medium, residences, neighbours or industries close to the plant, infrastructure
	dispersion routes	puffs and plumes by air (combustion products, gaseous release) heavy gases by air (gaseous release) liquids by sewer system to public waste water treatment plant liquids to soil (subsoil water) liquids to marine recipients (e.g. streams, lakes)
	meteorological and topographical factors	predominant wind direction and speed predominant weather conditions surface roughness buildings and obstructions
RESOURCES	personnel directly involved in the activity	normally less than 50
	technical configuration	plant units, storages, utility systems
	amount and number of chemical substances	normally few and well-known by the plant personnel
	construction materials	steel, plastics, insulating materials, concrete etc.
	electrical supply system	public supply system
	communication system	e-mail, phone, fax
	transport system	internal transport system (truck, lorry, pipelines)
PROCESS CONDITION	energy potential	large amount of flammable and reactive substances can be present
	temperature, high/low	liquids/gases at high/low temperatures in separate plant units
	pressure, high/low	liquids/gases at high/low pressures in separate plant units
SYSTEMS CONTROL	automation	high on process operations
	instrumentation	normally high degree of instrumentation (alarms, process conditions)
	on-line control	high degree on process operations
	process control	registration and regulation of process parameters (pressure, flow, temperature, concentration, level)
	operator supervision	control room supervision, field supervision
	safety systems, confinements	e.g. containment, sprinkler system, spill basin, dikes
ORGANISATION	work organisation	strategic level: directors (managing, technical etc.) tactic level: head of departments (production, maintenance, environment etc.) operation level: operator, operation leader, managing engineers
	safety organisation	safety officer safety, health and welfare committees safety groups

STATUS (II)		PROCESS PLANT
SOURCES OF INFORMATION	system documentation	technical configuration of the plant, PI diagrams, flow charts, process descriptions, procedures, instructions, safety systems, internal emergency plans
	literature	e.g. information about chemical substances, component reliability data
	accident descriptions	accident/incident/near misses occurred at the plant or at similar plants
	information from organisations/consultants	specific analyses and investigations (risk analysis, health hazards, environmental hazards)
	information from authorities	external emergency plans, legislative requirements and approvals
	validation of information and sources	information up to date, information available
ANALYSIS METHODS	structural aspects	plant design, plant layout, component reliability, structural reliability of containment, machinery reliability
	operational aspects	process conditions, process parameters, control system, human reliability assessment of procedural tasks, instructions and procedures
	managerial aspects	qualification of personnel, fields of responsibility, information channels, safety culture, working discipline, resource allocation, decision-making hierarchy, interaction with other socio-technical systems (e.g. authorities, organisations), public relations

CONTEXT (I)		PROCESS PLANT
INCIDENT	hazard source	flammables, explosives, corrosives, toxic/radioactive substances, reactive chemicals, high/low pressure, high/low temperature
	loss of confinement	containment failure, leakage, external damage to equipment, change of pressure
	uncontrolled flow of energy	high/low temperature, high/low pressure, reaction energy, missile
	potential exposure	fire, explosion, release of toxic/radioactive substances
VULNERABLE OBJECTS	people threatened in high risk zones	personnel, neighbours, passers-by (mostly people who on beforehand can receive information about the hazards, alarms and the emergency plans)
	people that might be affected	people momentary staying in the risk zone
	environmental impacts (recipients)	threatened recipients will be known by the plant personnel and the authorities
	impact on property	process plant, infrastructure, buildings/houses outside the plant
	areas affected by the incident (source distance)	normally max. 1 km from the source, damages normally limited to one municipality
SCENARIO	incident mechanisms	equipment malfunction, containment failure, human error, external event, leakage etc.
	initiating events/upsets	equipment malfunction, human error, chemical reaction

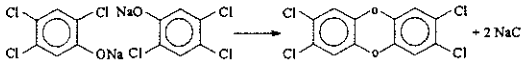
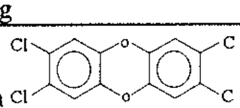
CONTEXT (II)		PROCESS PLANT
SCENARIO (continued)	external events	e.g. traffic problems, insufficient knowledge about the incident, bad weather conditions
	event sequences (intermediate events)	e.g. change in tank pressure, detection failure, alarm failure, cooling water omitted, wrong reaction mixture, operator error
	escalation - domino effects	escalation possible to other plant units or neighbours
	duration of event sequences	can be very short - less than 10 minutes /even momentary - from the initiating event till the uncontrolled energies are released
	systems response to events/upsets	safety system response: relief valves, utilities, components mitigation system response: vents, dikes, flares, sprinklers contingency system response: detection, alarms, procedures
	operator response to events/upsets	planned/ad hoc operations personnel safety equipment
	substances formed during the incident	many different chemical substances can be formed during a fire or during unwanted chemical reaction courses
EMERGENCY SUPPORT	basic ways of controlling/fighting the UFOE(s)	evacuate people threatened to exposure, stop traffic to area, cover with foam, cover leak, neutralising agent, lead water from fire fighting away from sensitive recipients
	emergency organisations	planned, dedicated
	special equipment	e.g. emergency treatment of people exposed to toxic chemicals, fire fighting equipment for special application (e.g. water reactive chemicals)
	mitigation systems	e.g. transportable basins for collection of water from fire fighting
	escape routes	normally described in the internal emergency plan
	alarms	local warning and emergency system (the plant unit) internal warning and emergency system (the company area) external warning and emergency (neighbours, authorities)
	inventories	number of people employed, head on duty, chemicals at the plant, plant layout
	communication lines	contacts to leader of the emergency operation, contact to head on duty, contact between police and fire brigade, contact to hospitals
	lines of command	head on duty, head of fire brigade, head of police
	requirements to personnel qualification	knowledge about handling of chemical substances
	contacts to experts	specific knowledge about chemicals
	possibilities for an efficient emergency control	primary victims can be difficult to rescue, accident escalation may be avoided if the emergency forces are on-site within ½ hour

TRAINING		PROCESS PLANT
TRAINING OBJECTIVES	time aspects for on-site operations	a fast operation is normally needed, the emergency organisations must be at the incident location less than ½ hour after the incident has occurred
	priority of decisions and actions	saving lives, protect environment, evacuation, protect property
	critical conditions	chemicals involved, amount of chemicals, temperatures, pressures
	constraints on access to incident location	emergency situations are normally taken into account in the plant layout
	early warning of people	internal emergency organisation, police
	evacuation (transport of injured persons)	the accident course may develop fast and a fast evacuation is needed
	measures for environmental protection	knowledge about chemical substances, knowledge about dispersion routes, knowledge about meteorological conditions
	operations by internal emergency organisation	early detection of an incident, fast call for an emergency, first aid, mitigation measures
	operations by external emergency organisations	communication, co-operation, mitigation measures, evacuation
	fields of responsibilities	primary emergency operations by the internal emergency organisation, transferring the responsibility from the internal to the external emergency organisation, subsequent emergency operations by the external emergency organisations
	communication with the public	information to relatives, neighbours, authorities
	co-operation between organisations	between internal and external emergency organisations, between external emergency organisations (fire brigade, police, hospitals, ambulance service)
PARTICIPANTS	trainees	plant safety officer, plant managers/engineers, heads of external emergency organisations, key decision makers
	supervisors	external or internal experts
	evaluators	representatives from the company, the authorities, the emergency organisations, training experts
DATA ACQUISITION	logging	computer logs, video/audio tape recordings
	observations	working climate, stress factors

STATUS (I)		**PROCESS PLANT** Release of dioxin at ICMESA Seveso, Italy, 10 July 1976
TERRITORY CHARACTERISTICS	area (e.g. urban, industrial, rural)	urban, industrial, 20 km from Milan
	population density	38.000 persons living in the most contaminated area next to the plant 222.000 persons in 11 towns affected (including a control belt)
	dispersion routes	air
	meteorological and topographical factors	the Milan-Como highway passes the site
RESOURCES	personnel directly involved in the activity	operators, shift foreman
	technical configuration	reactor (volume 13875 l) agitator with 2 impellers steam heated/water cooled limpet coils reactor equipped for vacuum distillation bursting disc (limit 3,5 bar)
	amount and number of chemical substances	2000 kg tetrachlorobenzene reacts with 1000 kg NaOH into 2030 kg trichlorphenol (sodium salt) and 541 kg NaCl with 3235 kg $HO\text{-}CH_2CH_2\text{-}OH$ as solvent and 609 kg xylene  as azeotropic agent 
	construction materials	stainless steel
	electrical supply system	-
	communication system	-
	transport system	-
PROCESS CONDITION	energy potential	high (exothermic reaction)
	temperature, high/low	158 °C to 450-500 °C
	pressure, high/low	bursting disc: rupture at 3,5 bar
SYSTEMS CONTROL	automation	no automatic controls
	instrumentation	temperature recorder
	on-line control	-
	process control	temperature recorder turned off at the time of the release
	operator supervision	not at the time of the release
	safety systems, confinements	reactor vessel, building
ORGANISATION	work organisation	-
	safety organisation	-
SOURCES OF INFORMATION	system documentation	-
	literature	-
	accident descriptions	similar accident but no external release at COALITE in the UK with ethylenglycol and dichlorobenzene as solvents, heated by hot oil similar accident but no external release at BASF in Germany with methanol as solvent in pressurised vessel

STATUS (II)		PROCESS PLANT Release of dioxin at ICMESA Seveso, Italy, 10 July 1976
	information from organisa-tions/consultants	-
	information from authorities	-
	validation of information and sources	previous accidents well known
ANALYSIS METHODS	structural aspects	no trapping/scrubbing of any material released from the reactor no automatic emergency equipment
	operational aspects	no hydraulic tests of vessel no inspection of bursting disc
	managerial aspects	measures had been taken to avoid similar condi-tions as at BASF and COALITE hot vessel allowed to be left without supervision

CONTEXT (I)		PROCESS PLANT Release of dioxin at ICMESA Seveso, Italy, 10 July 1976
INCIDENT	hazard source	formation of dioxin at around 180 °C. Exother-mic reaction → increased temperature and yield of dioxin dioxin is very stable and highly toxic, teratogenic (embryotoxic), carcinogenic, mutagenic, causes chemical burns and chloracne
	loss of confinement	bursting disc, release to environment
	uncontrolled flow of energy	runaway reaction
	potential exposure	release of highly toxic chemical
VULNERABLE OBJECTS	people threatened in high risk zones	10 maintenance men and 19 contractors on the plant 670 persons living next to the plant (contamination zone A) people developed chemical burns and chloracne pregnant women had spontaneous abortions
	people that might be affected	38.000 persons living in the contamination zones A, B, R (R = no risk zone) 222.000 persons living in the area
	environmental impacts (recipients)	contamination of vegetables, soil, houses, roads animals and pets in the area received lethal doses
	impact on property	-
	areas affected by the incident (source distance)	5 $\mu g/m^2$ decided as acceptably safe contamination zone A 108 HA (mean 192,2 $\mu g/m^2$) contamination zone B 269 HA (mean 3 $\mu g/m^2$) contamination zone R 1430 HA (mean 0,9 $\mu g/m^2$) total area including control zones 9381 HA

CONTEXT (II)		PROCESS PLANT Release of dioxin at ICMESA Seveso, Italy, 10 July 1976
SCENARIO	incident mechanisms	exothermic reaction:  probably caused by radiant heat (superheated steam at 300 °C used during distillation) from uncovered part of the reactor walls on the top layer of the reaction mixture
	initiating events/upsets	?
	external events	weather conditions (many persons can be outside and be exposed to the release) traffic density (rush hour, holiday traffic)
	event sequences (intermediate events)	hydroxylation process finished → 15% ethylene glycol distilled off (50% required by operating procedures) → no water added (3000 litres required by operating procedures to cool the reaction mixture) → 15 minutes stir (operating procedures requires continuos stir until the reaction mixture is cold) → temperature recorder turned off, all power turned off → unit left, closed down for the weekend (contradictory to operating procedures) → rupture of bursting disc → actions by shift foreman: cooling water to limpet coils, dumping of 3000 litres water into the reactor, reflux condenser into service → release stopped
	escalation - domino effects	-
	duration of event sequences	**10. July**: ca. 06.00: reactor shut down and left at 158 °C; 12.37: rupture of bursting disc; ca. 12.57: cease of release **11. July**: local authorities informed about the release **12. July**: production resumed at the plant **16. July**: workers on strike, first cases of severe chloracne brought to hospital, plant ordered to close by the mayor of Seveso **19. July**: official announcement of the release of 2 kg dioxin, confirmed by laboratory data **23. July**: the company recommends evacuation **26. July**: evacuation initiated **2. August**: official order to evacuate
	systems response to events/upsets	when all power is turned off no systems are capable of going into action
	operator response to events/upsets	execution of a shut down procedure to a complete and safe shut down recognising the dangers of leaving a warm reaction mixture (unexpected reaction) initiating cooling
	substances formed during the incident	2-2½ kg dioxin 

CONTEXT (III)		PROCESS PLANT Release of dioxin at ICMESA Seveso, Italy, 10 July 1976
EMERGENCY SUPPORT	basic ways of controlling/fighting the UFOE(s)	limit/stop source
	emergency organisations	police, hospitals, walk-in laboratories staffed with volunteers, emergency assistance officers, Special Office at Seveso co-ordinates all activities
	special equipment	-
	mitigation systems	-
	escape routes	-
	alarms	-
	inventories	-
	communication lines	shift foreman → company official → local authorities
	lines of command	?
	requirements to personnel qualification	knowledge of dangers at a chemical plant
	contacts to experts	State Technical-Scientific Committee, International Scientific Committee Hoffman-La Roche laboratories in Zurich
	possibilities for an efficient emergency control	the delayed response of the company and the authorities caused prolonged exposure to dioxin in the affected areas

TRAINING (I)		PROCESS PLANT Release of dioxin at ICMESA Seveso, Italy, 10 July 1976
TRAINING OBJECTIVES	time aspects for on-site operations	fast response necessary to prevent exposure to the emitted substances
	priority of decisions and actions	limit source, warning of people, first aid
	critical conditions	amount of chemicals
	constraints on access to incident location	emergency personnel will be exposed to dioxin
	early warning of people	plant → police → radio, TV
	evacuation (transport of injured persons)	855 persons: all from zone A, children and pregnant women from zone B
	measures for environmental protection	preventing further distribution of the released material by limiting traffic in and out of the contaminated area collection and storage/destruction of contaminated agricultural products applying chemicals to surfaces to facilitate the degradation of dioxin
	operations by internal emergency organisation	controlling the accident/release inform authorities and neighbours provide information about the released substances damage assessment clean up action

TRAINING (II)		PROCESS PLANT Release of dioxin at ICMESA Seveso, Italy, 10 July 1976
TRAINING OBJECTIVES (continued)	operations by external emergency organisations	inform public treatment of persons exposed to the released material control/limit access to affected area clean up action provide rehousing facilities
	fields of responsibilities	plant personnel → local authorities → emergency task force
	communication with the public	information officer at headquarters of emergency operation
	co-operation between organisations	task force backed up by technical and chemical experts
PARTICIPANTS	trainees	-
	supervisors	-
	evaluators	-
DATA ACQUISITION	logging	-
	observations	-

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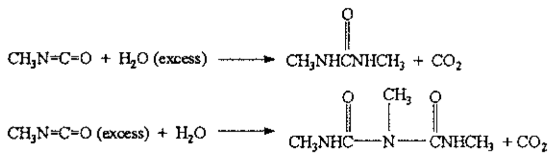
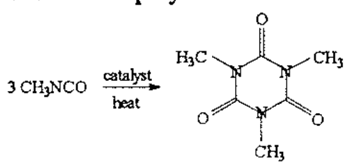
STATUS (I)		PROCESS PLANT Release of methyl isocyanate at Union Carbide Bhopal, India, 3 December 1984
TERRITORY CHARACTERISTICS	area (e.g. urban, industrial, rural)	urban, industrial
	population density	900.000 people in Bhopal 100.000 in shantytowns Jayaprakash Nagar and Kali Parade adjacent to the plant
	dispersion routes	air
	meteorological and topographical factors	hilly area with a small declination towards the railway station and downtown area north-westerly wind 1-2 m/s, temperature 7-10 °C, inversion
RESOURCES	personnel directly involved in the activity	one supervisor, six operators on a night shift
	technical configuration	refrigeration of underground storage tank (partly covered with concrete) vent scrubber with sodium hydroxide solution NaOH
	amount and number of chemical substances	40 tonnes methyl isocyanate (MIC) $CH_3N=C=O$
	construction materials	steel (stainless steel 403 required), concrete
	electrical supply system	-
	communication system	walkie-talkie, telephone
	transport system	-
PROCESS CONDITION	energy potential	normally low
	temperature, high/low	storage temperature around 0 °C must not exceed 15 °C
	pressure, high/low	storage at atmospheric pressure
SYSTEMS CONTROL	automation	no
	instrumentation	pressure gauge temperature gauge no pressure and temperature alarms
	on-line control	no
	process control	manual logging by operators
	operator supervision	yes
	safety systems, confinements	refrigeration system on underground storage tanks (freon-22) reserve storage tank (one out of three must be empty) scrubber system flare tower sprinkler system
ORGANISATION	work organisation	planned number per shift: 1 superintendent exclusively for MIC plant, 3 supervisors, 2 maintenance supervisors, 12 operators actual number: 1 superintendent for the whole factory, 1 supervisor, no maintenance supervisors, 6 operators
	safety organisation	no emergency plan at the factory

STATUS (II)		PROCESS PLANT Release of methyl isocyanate at Union Carbide Bhopal, India, 3 December 1984
SOURCES OF INFORMATION	system documentation	-
	literature	procedures for handling, shipping, storage, use of MIC inadequate information about toxicity of MIC information about runaway danger not available/communicated
	accident descriptions	1978: fire at naphtha-storage area 1981: worker killed by a phosgene leak; 24 people severely ill by phosgene leak 1982: pipe rupture and gas leak into shantytowns 1983: two minor leaks 1984: worker with chemical allergy died
	information from organisations/consultants	safety audit report (did not identify problems at the MIC unit)
	information from authorities	-
	validation of information and sources	-
ANALYSIS METHODS	structural aspects	storing large quantities of MIC; capacity of vent gas scrubber insufficient; refrigeration plant not functioning (CFC removed); no automatic censors for MIC storage tanks; temperature gauge not functioning (pressure gauge ?); flare tower disconnected steel pipelines used instead of stainless steel pipelines; no reading of position of valves in control room; computerised early warning and fail-safe system on similar US plant not installed
	operational aspects	vent gas scrubber only in action when needed; no communication hot-lines corroded valves not changed; reduction in operating staff; large employee turnover and poor training → inexperienced operators
	managerial aspects	emphasis on profits; highly centralised decision-making; plant modified without performing a risk analysis; treating hazardous and non-hazardous facilities alike safety audit results not communicated to the plant; no improvement of safety after previous accidents at the plant; poor on-site emergency planning

CONTEXT (I)		**PROCESS PLANT** Release of methyl isocyanate at Union Carbide Bhopal, India, 3 December 1984
INCIDENT	hazard source	water contaminated with substances (rust, salt, metals) can catalyse an exothermic polymerisation heat → increased pressure → release of MIC which is an extremely irritating compound with a high degree of inhalation toxicity
	loss of confinement	refrigeration system out of order reserve storage tank was not used scrubber system closed down for maintenance flare tower disconnected sprinkler system only effective up to 15 m beyond ground level; MIC release at 33 m
	uncontrolled flow of energy	runaway reaction in MIC underground storage tank
	potential exposure	extreme toxic isocyanate gas (cough, increased mucus discharge, salivation, lachrymose, cramping of the eyelids, feeling of suffocation, oedema)
VULNERABLE OBJECTS	people threatened in high risk zones	130.000 treated at hospitals in Bhopal 40.000 evacuees treated at hospitals outside Bhopal
	people that might be affected	320.000 affected
	environmental impacts (recipients)	1.600 animal carcasses → cholera danger
	impact on property	none
	areas affected by the incident (source distance)	severely affected area 6-7 km^2 affected area 25 km^2
SCENARIO	incident mechanisms	exothermic reaction with water:  exothermic polymerisation: 
	initiating events/upsets	small amounts of water caused an exothermic hydrolysis
	external events	weather/meteorological conditions, at low temperatures the MIC condenses and causes additional contamination number of people trying to evacuate → traffic density availability to emergency equipment

CONTEXT (II)		PROCESS PLANT Release of methyl isocyanate at Union Carbide Bhopal, India, 3 December 1984
SCENARIO (continued)	event sequences (intermediate events)	**alt 1.** attempt to pressurise and transfer MIC from tank 610 to the processing facility → failure to pressurise → another attempt to pressurise fails → plant supervisor orders washing the MIC lines → washing without insertion of slip plates → water enters the relief valve vent header → water enters the process vent header via the jumper (modification to original design) → water in MIC storage tank → ..... **alt 2.** water hose connected directly to MIC storage tank (sabotage) → ..... **both cases:** water in MIC storage tank → hydrolysis and polymerisation of MIC → sharp rise in temperature and pressure → rupture of safety valve → attempt to start vent gas scrubber pump → failure → plant superintendent informed → toxic gas leak alarm sounds → turned off → police patrol reports that something is wrong at Union Carbide → city police chief informed → police contacts Union Carbide, staff reports that nothing is abnormal. Additional District Magistrate of Bhopal informs the Works manager of Union Carbide. Safety valve reseated and siren sounded at full blast → emergency operation
	escalation - domino effects	other parts of the plant were not involved
	duration of event sequences	**26 November** first attempt to pressurise tank 610 **2 December** second attempt to pressurise tank 610 21.15: washing of lines started; 21.20: pressure in tank 610 about 0,14 bar; 21.45: pressure in tank 610 0,7 bar (logged by operator); 22.30-22.45: first detection of gas leak, people starts evacuating the shantytowns; 23.50: operator notices yellow drip from the relief valve vent header **3 December** around midnight: order to stop washing operations 00.20: safety valve ruptures (2,7 bar), attempt to start scrubber pump; 00.25: temperature of concrete cover about 300 °C; 00.40: first report of MIC leaking through the vent line; 01.00: public siren sounded for a few minutes, police patrol reports something wrong; 01.15: city police chief informed, Union Carbide reports nothing abnormal; 01.45: Works manager informed; 02.00-02.30: safety valve reseated; ca. 02.00: hospitals alerted; 02.30: public siren sounded at full blast

CONTEXT (III)		**PROCESS PLANT** Release of methyl isocyanate at Union Carbide Bhopal, India, 3 December 1984
SCENARIO (continued)	systems response to events/upsets	safety systems in order and in function early warning of malfunctions
	operator response to events/upsets	initiate preventive measures inform about the accident and the released substance(s) as soon as possible
	substances formed during the incident	30 tonnes MIC released during 1 hour, 15 tonnes left in the tank as polymer small amounts of phosgene (inhibits polymerisation)
EMERGENCY SUPPORT	basic ways of controlling/fighting the UFOE(s)	sprinkler system scrubber system (NaOH) decrease pressure by transfer to reserve storage tank
	emergency organisations	fire department, police, 5 hospitals, volunteer clinics, mobile treatment centres, government outpatient facilities, World Health Organisation
	special equipment	means for provision of large quantities of uncontaminated water trucks and cranes for removal of animal carcasses
	mitigation systems	vent gas scrubber (shut down for maintenance, NaOH solution weak) flare tower (shut down for maintenance, corroded piping) water curtain (shoots a jet of water 12-15 meters high, MIC released at 33 meters) refrigeration system (shut down, the refrigerant had been removed for use elsewhere) spare tank (not used/valves not opened)
	escape routes	roads railway junction paralysed for 20 hours → escape by train not possible
	alarms	a loud continuos siren for public warning of gas leaks a muted siren over the factory public address system for employees only
	inventories	medical equipment and medicine
	communication lines	poor emergency communication
	lines of command	ad hoc
	requirements to personnel qualification	knowledge about possible release of toxic gasses/chemicals from the plant medical knowledge toxicological knowledge
	contacts to experts	toxicologists
	possibilities for an efficient emergency control	no specific antidote for MIC lack of sufficient means for transportation lack of hospital capacity lack of medical equipment during the first hours of the accident additional medical equipment and staff provided from other cities

TRAINING		PROCESS PLANT Release of methyl isocyanate at Union Carbide Bhopal, India, 3 December 1984
TRAINING OBJECTIVES	time aspects for on-site operations	a fast response is necessary to identify/control/stop the runaway reaction and subsequent release of MIC
	priority of decisions and actions	limit/control release, first aid, evacuate people
	critical conditions	amount of toxic chemicals, wind direction
	constraints on access to incident location	sufficient gas masks not available more MIC condensed out of the sky on the following night
	early warning of people	early recognition of accident and information to authorities public knowledge about the purpose of the public siren
	evacuation (transport of injured persons)	during the first hours of the accident individual initiative by foot, busses, trucks, vans, private cars several severe traffic accidents provision of means for transportation: evacuees and injuries
	measures for environmental protection	prevention of release
	operations by internal emergency organisation	provide emergency response plans/procedures/training (provide updated risk analyses)
	operations by external emergency organisations	provide emergency response plans/procedures/training
	fields of responsibilities	factory → emergency response centre (police or fire department) police in charge of emergency response, but police station not operational → no efficient emergency co-ordination by the police
	communication with the public	missing-persons bureau person(s) with sufficient knowledge about the accident and the released substance(s) and protective measures to be taken
	co-operation between organisations	poor/none civil defence not mobilised alternative locations for the emergency response centre means for communication between emergency organisations
PARTICIPANTS	trainees	-
	supervisors	-
	evaluators	-
DATA ACQUISITION	logging	-
	observations	-

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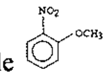
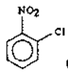
STATUS		**PROCESS PLANT** Chemical accident at Griesheim production plant Hoechst AG, 22 February 1993
TERRITORY CHARACTERISTICS	area (e.g. urban, industrial, rural)	urban, industrial
	population density	high
	dispersion routes	air
	meteorological and topographical factors	residential area, forest and river
RESOURCES	personnel directly involved in the activity	operator, shift foreman
	technical configuration	reactor vessel with agitator heating/cooling jacket 2 safety valves connected to an outside blow-off pipe to the atmosphere
	amount and number of chemical substances	5,8 tonnes ortho-nitroanisole  16 tonnes methanol CH_3OH 2,2 tonnes sodium chloride NaCl 0,6 tonnes sodium hydroxide NaOH
	construction materials	-
	electrical supply system	-
	communication system	telephone
	transport system	-
PROCESS CONDITION	energy potential	low
	temperature, high/low	95 °C - 155 °C
	pressure, high/low	9 bar - 16 bar lift-off limit for safety valves
SYSTEMS CONTROL	automation	low
	instrumentation	measurement of temperature and pressure
	on-line control	yes
	process control	recording of agitator power consumption recording of temperature
	operator supervision	yes
	safety systems, confinements	reactor vessel, safety valves control system (temperature, agitation)
ORGANISATION	work organisation	shift foreman → operators
	safety organisation	-
SOURCES OF INFORMATION	system documentation	-
	literature	safety analysis scenarios does not cover this specific accident
	accident descriptions	-
	information from organisations/consultants	-
	information from authorities	Federal Emissions Protection Law
	validation of information and sources	safety analysis examined by an expert for the Commercial Supervisory Office, Frankfurt
ANALYSIS METHODS	structural aspects	continuos stirring of the reaction mixture is necessary to ensure a homogenous and controllable reaction
	operational aspects	agitator turned on manually no warning signal that agitator is not turned on
	managerial aspects	it was not considered that an experienced operator could make such a serious mistake

CONTEXT (I)		PROCESS PLANT Chemical accident at Griesheim production plant Hoechst AG, 22 February 1993
INCIDENT	hazard source	ortho-nitroanisole is toxic, carcinogenic and mutagenic
	loss of confinement	release of reaction mixture through safety valves and blow-off pipe
	uncontrolled flow of energy	run-away reaction
	potential exposure	toxic, carcinogenic and mutagenic substances
VULNERABLE OBJECTS	people threatened in high risk zones	-
	people that might be affected	people in the residential area Frankfurt-Griesheim, -Schwanheim, -Goldstein
	environmental impacts (recipients)	the River Main, public highways, houses, soil and plants in the residential area
	impact on property	equipment not damaged
	areas affected by the incident (source distance)	-
SCENARIO	incident mechanisms	incomplete mixture of reaction components because the agitator was not turned on, when the agitator was turned on the exothermic reaction progressed very quickly
	initiating events/upsets	insufficient mixing of chemicals
	external events	number of people out-doors, traffic density, weather conditions, water level in river
	event sequences (intermediate events)	methanol and  ortho-nitroclorobenzene fed and mixed → agitator turned off → level checked → reactor closed and nitrogen added → reactor heated to prescribed temperature → methanol and sodium hydroxide pumped into reactor → sample taken from the reactor → different from normal → temperature lowered → agitator turned on → rapid acceleration of the reaction producing ortho-nitroanisole → rise in temperature and pressure → release of reaction mixture through safety valves → fallout in neighbouring area
	escalation - domino effects	-
	duration of event sequences	04.15: release of reaction mixture
	systems response to events/upsets	alarm/indication when agitator is turned off during operation
	operator response to events/upsets	recognise conditions for a run-away reaction, warning the emergency services
	substances formed during the incident	-
EMERGENCY SUPPORT	basic ways of controlling/fighting the UFOE(s)	limit/stop source, redirect release
	emergency organisations	Frankfurt Police, Frankfurt Fire Brigade, Hoechst company fire service
	special equipment	-
	mitigation systems	-
	escape routes	-
	alarms	-

CONTEXT (II)		**PROCESS PLANT** Chemical accident at Griesheim production plant Hoechst AG, 22 February 1993
EMERGENCY SUPPORT (continued)	inventories	-
	communication lines	Hoechst AG → (lack of timely information to) authorities → neighbours/public circuitous route: 16th Police Dept. → Frankfurt Police HQ. Local Co-ordinating Centre, Frankfurt fire brigade → Hoechst AG company fire service
	lines of command	?
	requirements to personnel qualification	-
	contacts to experts	engineers, natural scientists, toxicologists expert team: interministerial working party concerned with damage assessment, toxicological evaluation, short-term/medium-term actions
	possibilities for an efficient emergency control	cleaning houses, cars and roads removal of soil and vegetation (and in a few cases asphalt) mowing grass disposal of polluted waste water

TRAINING		PROCESS PLANT Chemical accident at Griesheim production plant Hoechst AG, 22 February 1993
TRAINING OBJECTIVES	time aspects for on-site operations	a large area had to be cleaned very quickly
	priority of decisions and actions	limit source, warning of people, first aid, collect waste water, cleaning
	critical conditions	amount of chemicals
	constraints on access to incident location	roads closed because they were contaminated with a sticky yellow-brown mass
	early warning of people	radio, TV, police
	evacuation (transport of injured persons)	some persons received medical attention ambulance service, private cars
	measures for environmental protection	removing soil, vegetables, bushes, mowing grass to prevent seepage into the ground water disposal of polluted waste water from the cleaning of houses and surfaces
	operations by internal emergency organisation	controlling/stopping the accident warn authorities and neighbours about the release provide necessary information about the accident and the released substance(s) clean up polluted area
	operations by external emergency organisations	controlling/limiting/preventing access to contaminated area collection of test samples transportation of injuries information to the public clean up polluted area
	fields of responsibilities	internal emergency organisation → external emergency organisation → joint working party (task force) Hoechst AG → authorities/joint working party → Minister of State
	communication with the public	? criticised in the report, no details
	co-operation between organisations	Hoechst AG and joint working party with representatives of the City of Frankfurt and the Federal State, supported by the expert team, plans the actions to be taken
PARTICIPANTS	trainees	-
	supervisors	-
	evaluators	-
DATA ACQUISITION	logging	-
	observations	-

Reference "Chemical accident at Griesheim production plant, Hoechst AG, 22 February 1993":

Report *on the chemical accident at the Griesheim production plant of Hoechst AG on 22 February 1993,* Ministry of the Environment, Energy and Federal Affairs of the German Federal State of Hesse, March 1993, report XI/347/93-EN, 46 pp.

APPENDIX B

Storage

Accidents

Jenova - ammonia tank failure (1989, Lithuania)
San Juanico - gas explosion (1984, Mexico)
Basle - warehouse fire (1986, Switzerland)

STATUS (I)		STORAGE
TERRITORY CHARACTERISTICS	area (e.g. urban, industrial, rural)	urban or industrial
	population density	high ⇨ medium, residences or industries close to the storage
	dispersion routes	puffs and plumes by air (combustion products, gaseous releases) heavy gases by air (gaseous releases) liquids by sewer system to public waste water treatment plant liquids to soil (subsoil water) liquids to marine recipients (e.g. streams, lakes)
	meteorological and topographical factors	predominant wind directions and speed predominant weather conditions, atmosphere stability surface roughness, buildings and obstructions storage layout, neighbours (e.g. schools, companies), infrastructure
RESOURCES	personnel directly involved in the activity	normally less than 10
	technical configuration	facilities for transferring of chemicals e.g. from lorry/ship to storage and vice versa, pipelines, tanks, vessels, utility systems
	amount and number of chemical substances	large amount of chemicals, normally few in number and well-known by the personnel
	construction materials	steel, plastics, insulating materials, concrete etc.
	electrical supply system	public supply system
	communication system	e-mail, phone, fax
	transport system	internal transport system (truck, lorry, pipelines)
PROCESS CONDITION	energy potential	large amount of flammable substances can be present
	temperature, high/low	liquids/gases at high/low temperatures in separate storage tanks
	pressure, high/low	liquids/gases at high/low pressures in separate storage tanks
SYSTEMS CONTROL	automation	low
	instrumentation	low, fire alarms may be installed
	on-line control	low
	process control	registration of storage conditions (e.g. pressure, temperature, level)
	operator supervision	low
	safety systems, confinements	storage building, containers, vessels, spheres, fire detection and fighting system
ORGANISATION	work organisation	operator, operation leader, managing engineer, director
	safety organisation	safety officer
SOURCES OF INFORMATION	system documentation	technical configuration of the storage tanks, PI diagrams, procedures, instructions, safety systems, internal emergency plans
	literature	e.g. information about chemical substances, component reliability data, structural reliability of storage tanks, stress corrosion
	accident descriptions	accident/incident/near misses occurred at the storage or at similar installations

STATUS (II)		STORAGE
SOURCES OF INFORMATION (continued)	information from organisations/consultants	specific analyses e.g. risk analysis, health hazards, environmental hazards
	information from authorities	external emergency plans, legislative requirements and approvals
	validation of information and sources	information up to date, information available
ANALYSIS METHODS	structural aspects	design and layout of the storage, component and structural reliability, storage conditions and parameters
	operational aspects	human reliability assessment of procedural tasks, qualification of personnel
	managerial aspects	fields of responsibility, information channels, safety culture, working discipline, resource allocation, decision-making hierarchy, interaction with other socio-technical systems (e.g. authorities, organisations), public relations

CONTEXT (I)		STORAGE
INCIDENT	hazard source	hazardous materials: flammables, explosives, corrosives, toxic/radioactive substances, reactive chemicals hazardous storage conditions: high/low temperature, high/low pressure, holding time, decomposition energy
	loss of confinement	fire of chemicals and building, rupture, leakage
	uncontrolled flow of energy (UFOE)	chemical energy, BLEVE (Boiling Liquid Expanding Vapour Explosion)
	potential exposure	fire, explosion, release of toxic/radioactive substances harm to humans, harm to environment, harm to materials and property
VULNERABLE OBJECTS	people threatened in high risk zones	personnel, neighbours, passers-by (mostly people who beforehand can receive information about the hazards, alarms and the emergency plans)
	people that might be affected	people staying in the vicinity
	environmental impacts (recipients)	threatened recipients will be known by the personnel and the authorities
	impact on property	damage to storage building, damage to neighbours (plant, housing), damage to infrastructure
	areas affected by the incident (source distance)	normally max. 1 km from the source
SCENARIO	incident mechanisms	equipment malfunction, containment failure, human error, external event, leakage etc.
	initiating events/upsets	equipment malfunction, human error
	external events	e.g. traffic problems, insufficient knowledge about the incident, escalation of the incident course, bad weather conditions
	event sequences (intermediate events)	safe storage ⇨ storage in disturbed state ⇨ storage in hazardous condition ⇨ dangerous disturbance to storage ⇨ fire, explosion, release ⇨ harm ⇨ emergency operation
	escalation - domino effects	escalation possible to other storage units or neighbours

CONTEXT (II)		STORAGE
SCENARIO (continued)	duration of event sequences	can be very short - less than 10 minutes /even momentary - from the initiating event until the substances are released
	systems response to events/upsets	safety system response: relief valves, utilities, components mitigation system response: vents, dikes, flares, sprinklers contingency system response: detection, alarms, procedures
	operator response to events/upsets	planned/ad hoc operations personnel safety equipment
	substances formed during the incident	many different chemical substances can be formed during a fire
EMERGENCY SUPPORT	basic ways of control-ling/fighting the UFOE(s)	cover with foam, fire fighting, evacuate, first aid, redirect flow (water from fire fighting)
	emergency organisations	planned, dedicated
	special equipment	e.g. emergency treatment of people exposed to toxic chemicals, fire fighting equipment for spe-cial application (e.g. water reactive chemicals)
	mitigation systems	e.g. collection of water from fire fighting
	escape routes	normally described in the internal emergency plan
	alarms	internal warning system at the storage external warning systems (neighbours, authori-ties)
	inventories	number of people employed, head on duty, chemicals stored, storage layout
	communication lines	contacts to leader of the emergency operation, contact to head on duty, contact to hospitals, contact between police and fire brigade
	lines of command	-
	requirements to personnel qualification	knowledge about handling of chemical sub-stances
	contacts to experts	specific knowledge about chemicals
	possibilities for an efficient emergency control	primary victims can be difficult to rescue, acci-dent escalation can be avoided if the emergency forces are on-site within ½ hour

TRAINING		STORAGE
TRAINING OBJECTIVES	time aspects for on-site operations	a fast establishment of an on-site emergency operation is normally needed the emergency organisations must be at the incident location less than ½ hour after the incident has occurred
	priority of decisions and actions	evacuate, reduce source, fire fighting, redirect flow, first aid
	critical conditions	chemicals involved, amount of chemicals, temperatures, pressures
	constraints on access to incident location	emergency situations are normally taken into account in the storage layout
	early warning of people	internal emergency organisation, police
	evacuation (transport of injured persons)	the accident course may develop fast and a fast evacuation is needed evacuation of people in high risk zones, transportation of injuries to hospital
	measures for environmental protection	knowledge about chemical substances, knowledge about dispersion routes, knowledge about meteorological conditions
	operations by internal emergency organisation	early detection of an incident, fast call for an emergency, first aid, mitigation measures
	operations by external emergency organisations	communication, co-operation, mitigation measures, evacuation
	fields of responsibilities	primary emergency operations by the internal emergency organisation, transferring the responsibility from the internal to the external emergency organisation, subsequent emergency operations by the external emergency organisations normally the head of the fire brigade is head of the emergency operation
	communication with the public	information about injuries and environmental impact information to relatives, neighbours, authorities
	co-operation between organisations	between internal and external emergency organisations, between external emergency organisations (fire brigade, police, personnel at the storage, hospital, authorities, ambulance service)
PARTICIPANTS	trainees	safety officer, managers/engineers, heads of external emergency organisations, key decision makers
	supervisors	external or internal experts
	evaluators	representatives from the company, the authorities, the emergency organisations, training experts
DATA ACQUISITION	logging	computer logs, video/audio tape recordings
	observations	working climate, stress factors

STATUS (I)		STORAGE Ammonia tank failure at the chemical site Azotas Ionava, Lithuania, 20 March 1989
TERRITORY CHARACTERISTICS	area (e.g. urban, industrial, rural)	military zone, restricted area
	population density	high: 3500 employees at the site at the time of the incident, about 40.000 inhabitants in Ionava (12 km north-east the site)
	dispersion routes	air
	meteorological and topographical factors	the wind was from the NE at 3-4 m/sec, temperature 8°C
RESOURCES	personnel directly involved in the activity	operators at the ammonia storage facility
	technical configuration	the tank was about 30 m diameter and 20 m tall standing on a concrete plinth supported by columns, volume 15322 m^3, capacity 10000 t liquid ammonia from the production unit at +10°C cooled to -33°C in a refrigeration unit and fed into the base of the tank ammonia off-gas was condensed and returned to the tank base via a refrigeration unit liquid ammonia was withdrawn from the tank base via centrifugal pumps to load rail cars
	amount and number of chemical substances	7000 t of liquid ammonia (-33°C) 15000 t NPK in a fertiliser storage situated close to the ammonia tank
	construction materials	carbon steel, wall thickness of 20 mm at the top and 35 mm at the base, thermally insulated with 700 mm of perlite covered by a steel jacket
	electrical supply system	-
	communication system	-
	transport system	-
PROCESS CONDITION	energy potential	high
	temperature, high/low	low, -33°C
	pressure, high/low	the tank vapour space working pressure range was 200-800 mm w.g.
SYSTEMS CONTROL	automation	-
	instrumentation	two ammonia off-gas piston type compressors with a capacity of 323 m^3/hr (one with electric motor drive and one with diesel engine) two breather valves for vacuum protection
	on-line control	continuous measuring of the pressure in the ammonia tank
	process control	the tank had an alarm and interlock system acting according to the ammonia gas pressure and liquid ammonia level
	operator supervision	-
	safety systems, confinements	two relief valves each with a capacity of 4200 m^3/hr, set point 1150 mm w.g. one flare with a burning capacity of 500 kg/hr tank walls
ORGANISATION	work organisation	-
	safety organisation	-

STATUS (II)		STORAGE Ammonia tank failure at the chemical site Azotas Ionava, Lithuania, 20 March 1989
SOURCES OF INFORMATION	system documentation	the ammonia tank and the ammonia plant were of Japanese design and they were installed in 1979 and 1969, respectively
	literature	-
	accident descriptions	-
	information from organisations/consultants	-
	information from authorities	-
	validation of information and sources	-
ANALYSIS METHODS	structural aspects	tank stability against dynamic shocks, continuous registration of the main variables of the refrigerated storage, records of start-up and shut-down data, automated disconnection of -30°C liquid ammonia supply into the bottom of the tank, capacity of flare flow rate, collection and evacuation of liquid ammonia spills
	operational aspects	ensure that the local emergency organisation has the necessary instructions for emergency situations
	managerial aspects	ensure that the necessary emergency measures are available

CONTEXT (I)		STORAGE Ammonia tank failure at the chemical site Azotas Ionava, Lithuania, 20 March 1989
INCIDENT	hazard source	large amounts of liquefied ammonia, large amounts of NPK
	loss of confinement	tank rupture, the shell of the ammonia tank smashed through the bound wall chemical fire
	uncontrolled flow of energy (UFOE)	evaporation, chemical energy, fire
	potential exposure	release of toxic gases due to evaporation and fire
VULNERABLE OBJECTS	people threatened in high risk zones	employees at the site: 7 people killed (4 construction workers, 2 employed at the site, 1 fire man from Vilnius) and 57 injured
	people that might be affected	people living in the area, inhabitants of Ionova, about 40000 people evacuated
	environmental impacts (recipients)	-
	impact on property	devastation around the tank and the NPK storage was enormous

CONTEXT (II)		STORAGE Ammonia tank failure at the chemical site Azotas Ionava, Lithuania, 20 March 1989
VULNERABLE OBJECTS (continued)	areas affected by the incident (source distance)	the ammonia vapour and the fertiliser decomposition (nitrous fumes) were spread up to 35 km forming a contamination zone with an area up to 400 km^2, at 5 km the cloud had the height of 100 m, at 10 km up to 400 m and at 20 km up to 200 m, about 12 km downwind ammonia concentration up to 250 ppm were measured
SCENARIO	incident mechanisms	14 t of warm (+10°C) ammonia liquid were moved into the tank in error and formed an unstable layer at the base of the tank; the ammonia did not evaporate as it was under hydrostatic pressure; the warm ammonia rose to the surface ("roll-over") which caused a sudden vapour generation in excess of the relief capacity; the refrigeration compressors were out of commission at the time; the local military fire brigade started to spray water which increased the ammonia evaporation and suddenly the ammonia cloud was ignited probably by a local flarestack
	initiating events/upsets	the tank was raised a little and thrown to a side for a distance of about 40 m the entire inventory of 7000 t refrigerated ammonia was released
	external events	-
	event sequences (intermediate events)	liquefied ammonia around the fertiliser factory and stores was in places 70 cm deep ammonia vapour cloud ignited
	escalation - domino effects	fire including the ammonia tank, control room, fertiliser factory and loading site; ignition of the fertiliser store with 15000 t NPK, self-sustaining combustion was initiated
	duration of event sequences	between 1100 hrs and 1115 hrs a "whooshing" noise was heard and the shell of the ammonia tank smashed; the local military fire brigade were at the scene within 5 minutes; the toxic gas alarm at the site was sounded 5 minutes after the incident; there were 12 fire fighters on the scene within 10 minutes; in the early afternoon it was decided to evacuate the town of Ionova; after 12 hours all the ammonia had evaporated but the fertiliser continued to decompose for three days evolving large quantities of nitrous fumes
SCENARIO (continued)	systems response to events/upsets	toxic gas alarm the fire fighters were on the site within few minutes but they were poorly equipped (only some old oxygen cylinders and masks were available) the civil defence of Lithuania has an emergency plan entitled "Ammonia 15" informing and recommending people to stay indoor
	operator response to events/upsets	-
	substances formed during the incident	ammonia vapour and nitrous fumes

CONTEXT (III)		STORAGE Ammonia tank failure at the chemical site Azotas Ionava, Lithuania, 20 March 1989
EMERGENCY SUPPORT	basic ways of controlling/fighting the UFOE(s)	fire fighting, cover with foam, evacuate, first aid
	emergency organisations	fire brigade, police, hospitals, civil defence
	special equipment	-
	mitigation systems	-
	escape routes	-
	alarms	toxic gas alarm
	inventories	-
	communication lines	-
	lines of command	-
	requirements to personnel qualification	-
	contacts to experts	-
	possibilities for an efficient emergency control	poor, the incident occurred very fast - within few minutes

TRAINING (I)		STORAGE Ammonia tank failure at the chemical site Azotas Ionava, Lithuania, 20 March 1989
TRAINING OBJECTIVES	time aspects for on-site operations	very fast operation is needed, evaporation and dispersion of ammonia can be fast
	priority of decisions and actions	evacuation of people at the site, first aid, evacuation of people in Ionava, fire fighting
	critical conditions	very large amount of ammonia and NPK bad emergency preparedness
	constraints on access to incident location	bad due to ammonia vapours, fires and damage of property
	early warning of people	not possible at the site, possible for Ionava ("Ammonia 15")
	evacuation (transport of injured persons)	about 200 brought to hospitals, about 40000 evacuated by bus
	measures for environmental protection	-
	operations by internal emergency organisation	local military fire brigade: control of ammonia evaporation, fire fighting, transportation of injuries
	operations by external emergency organisations	fire brigade of Vilnius: fire fighting, transportation of injuries, control of ammonia evaporation, decisions concerning evacuation
	fields of responsibilities	the managing director of Azotas responsible, he was supported by the civil defence
	communication with the public	the civil defence warned the people to stay indoor (radio, loudspeakers)
	co-operation between organisations	-

TRAINING (II)		**STORAGE** Ammonia tank failure at the chemical site Azotas Ionava, Lithuania, 20 March 1989
PARTICIPANTS	trainees	-
	supervisors	-
	evaluators	-
DATA ACQUISITION	logging	-
	observations	-

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STATUS (I)		STORAGE LPG-disaster at Petroleos Mexicanos, Pemex San Juan Ixhuatepec, 19 November 1984
TERRITORY CHARACTERISTICS	area (e.g. urban, industrial, rural)	industrial, 20 km north of Mexico City
	population density	high, the build-up area begins at a distance of 130 m from the storage tanks
	dispersion routes	air, ground level
	meteorological and topographical factors	at the time of disaster: wind speed 0,4 m/sec., temperature 7°C the territory shelves weakly against the build-up area the town San Juan Ixhuatepec is located in a 5 km long narrow valley
RESOURCES	personnel directly involved in the activity	6 Pemex operators at the site remote control by operators and the refinery 400 km from the distribution centre
	technical configuration	storage distribution centre the installation accommodated transhipment facilities for tank cars and railway tank cars as well as a gas bottling plant 2 spheres of 2400 m^3, 4 spheres of 1500 m^3, 48 horizontal cylinders of various dimensions (between 36 and 270 m^3), 2 ground flare pits, the centre was fed through three underground LPG-pipelines (12'', 4'', 4'') close to the Pemex storage to other storages were located (Unigas, Gasomatico)
	amount and number of chemical substances	liquefied propane and butane, total between 11.000 and 20.000 m^3
	construction materials	steel ?
	electrical supply system	-
	communication system	-
	transport system	-
PROCESS CONDITION	energy potential	high
	temperature, high/low	medium
	pressure, high/low	medium/high
SYSTEMS CONTROL	automation	remote control by the refinery 400 km away from the distribution centre
	instrumentation	pressure gauges installed at the pipelines between refinery and distribution centre, gas alarms were not installed
	on-line control	from refinery ?
	process control	-
	operator supervision	local supervision by the operators at the distribution centre
	safety systems, confinements	wall thickness of the larger spheres 37 mm, wall thickness of the cylinders 28 mm, pressure of pressure relief valves amounted to app. 10,3 bar fire protection system comprising pond, pumps and waterspray system
ORGANISATION	work organisation	-
	safety organisation	-

STATUS (II)		**STORAGE** LPG-disaster at Petroleos Mexicanos, Pemex San Juan Ixhuatepec, 19 November 1984
SOURCES OF INFORMATION	system documentation	plant description, the design of distribution centre followed American standards and the predominant part of the installation was produced in USA
	literature	-
	accident descriptions	-
	information from organisations/consultants	-
	information from authorities	the prosecuting authorities had several times in writing complained of a poor standard of maintenance for some older parts of the distribution centre
	validation of information and sources	-
ANALYSIS METHODS	structural aspects	the installation covered only a small area with the cylinders situated very close the build-up area was too close to the installation, a safety distance of at least 400 m is necessary in order to avoid ignition due to heat radiation gas alarms must be installed
	operational aspects	operators at hazardous installations must have the necessary education and training to handle irregular situations
	managerial aspects	poor communication between operators at refinery and operators at the distribution centre might have influenced the accident course poor standard of maintenance could have caused the leakage

CONTEXT (I)		**STORAGE** LPG-disaster at Petroleos Mexicanos, Pemex San Juan Ixhuatepec, 19 November 1984
INCIDENT	hazard source	large amount of flammable gases
	loss of confinement	rupture, leakage
	uncontrolled flow of energy	chemical energy, BLEVE (Boiling Liquid Expanding Vapour Explosion)
	potential exposure	fire, explosion, missile, heat radiation
VULNERABLE OBJECTS	people threatened in high risk zones	operators: 5 operators killed and 2 injured people living in the build-up area: app. 500 killed and over 7000 seriously injured the majority of casualties occurred within a distance of 300 m away from storage (heat radiation, vapour cloud, explosion, fire, lack of oxygen, shock wave, ground level fireballs, missiles) fragments from the spheres and cylinders were scattered about the area, 12 cylinders came down at distances of over 100 m, maximum distance 1.200 m
	people that might be affected	people living in San Juan Ixhuatepec

CONTEXT (II)		**STORAGE** LPG-disaster at Petroleos Mexicanos, Pemex San Juan Ixhuatepec, 19 November 1984
VULNERABLE OBJECTS (continued)	environmental impacts (recipients)	-
	impact on property	major damages to plant, neighbouring plants, infrastructure and housing (a vapour cloud explosion which might have caused overpressure effects and a BLEVE)
	areas affected by the incident (source distance)	the various explosions were registered on the seismograph of Mexico City University (app. 30 km away)
SCENARIO	incident mechanisms	LPG-leakage followed by ignition caused a chain of explosions which almost completely destroyed the storage
	initiating events/upsets	-
	external events	-
	event sequences (intermediate events)	in the early morning large amount of LPG leaked from a 8'' pipeline, the (heavy) LPG-gas dispersed into the surroundings, the vapour cloud had reached a visible height of about 2 m when it ignited, the ignition source was probable a flare pit, a flash fire resulted, nine explosions were registered
	escalation - domino effects	the neighbour storages Unigas and Gasomatico were partly damaged
	duration of event sequences	the initial explosion was registered at 5:45 a.m., the final one at 7:01 a.m. the second explosion (BLEVE) occurred one minute after the initial one
	systems response to events/upsets	-
	operator response to events/upsets	the operators tried to reduce the release of gas
	substances formed during the incident	combustion products
EMERGENCY SUPPORT	basic ways of controlling/fighting the UFOE(s)	fire fighting, evacuate, first aid
	emergency organisations	several fire brigades - total about 200 fire men - from neighbour municipalities participated in the fire fighting, water for fire fighting was pumped from 4 ponds each containing 1.600 m^3 of water, about 100 ambulances were at the location within one hour in total 4.000 rescue workers were involved (doctors, nurses, volunteers, firemen, police, ambulance service) 33 hospitals were involved
	special equipment	-
	mitigation systems	-
	escape routes	-
	alarms	gas alarms were not installed, not possible to warn people living close to the installation
	inventories	-
	communication lines	-

CONTEXT (III)		STORAGE LPG-disaster at Petroleos Mexicanos, Pemex San Juan Ixhuatepec, 19 November 1984
EMERGENCY SUPPORT (continued)	lines of command	-
	requirements to personnel qualification	-
	contacts to experts	-
	possibilities for an efficient emergency control	very bad

TRAINING		STORAGE LPG-disaster at Petroleos Mexicanos, Pemex San Juan Ixhuatepec, 19 November 1984
TRAINING OBJECTIVES	time aspects for on-site operations	very fast operation and evacuation are needed
	priority of decisions and actions	-
	critical conditions	large inventories of LPG in densely populated area
	constraints on access to incident location	flames, explosion, heat, gas chaos along roads leading to the area (fleeing people in one direction and rescue workers in the other)
	early warning of people	the operators registered the LPG-gas cloud and they tried to warn people to take refuge
	evacuation (transport of injured persons)	200.000 people were evacuated 363 ambulances and 5 helicopters were used for transportation of injured people
	measures for environmental protection	-
	operations by internal emergency organisation	-
	operations by external emergency organisations	fire fighting, transportation of injuries, first aid
	fields of responsibilities	-
	communication with the public	addressing the public under chaos
	co-operation between organisations	-
PARTICIPANTS	trainees	-
	supervisors	-
	evaluators	-
DATA ACQUISITION	logging	-
	observations	-

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STATUS		STORAGE Fire at warehouse 956 at the Muttenz Works Sandoz, Basle, Switzerland, 1 November 1986
TERRITORY CHARACTERISTICS	area (e.g. urban, industrial, rural)	industrial, urban
	population density	high, city of Basle
	dispersion routes	air, river Rhine
	meteorological and topographical factors	light wind from north-east
RESOURCES	personnel directly involved in the activity	none
	technical configuration	size of storage: 2 x 2.250 m^2 originally used for storing machinery and equipment
	amount and number of chemical substances	1250 tonnes chemicals including 40.000 l organic solvents, 60 tonnes pesticides, 150 kg mercury compounds
	construction materials	steel, asbestos cement, polyester
	electrical supply system	-
	communication system	-
	transport system	-
PROCESS CONDITION	energy potential	high
	temperature, high/low	low
	pressure, high/low	low
SYSTEMS CONTROL	automation	none
	instrumentation	none
	on-line control	none
	process control	none
	operator supervision	Sandoz safety personnel
	safety systems, confinements	storage building
ORGANISATION	work organisation	-
	safety organisation	-
SOURCES OF INFORMATION	system documentation	-
	literature	-
	accident descriptions	-
	information from organisations/consultants	-
	information from authorities	-
	validation of information and sources	-
ANALYSIS METHODS	structural aspects	heat detectors installed, fire extinguishers no sprinklers or smoke detectors installed no catch basins for fire extinguishing water
	operational aspects	flammable liquids not stored separately
	managerial aspects	design considered safe

CONTEXT (I)		**STORAGE** Fire at warehouse 956 at the Muttenz Works Sandoz, Basle, Switzerland, 1 November 1986
INCIDENT	hazard source	large amounts of flammable liquids
	loss of confinement	fire of chemicals and building
	uncontrolled flow of energy	chemical energy
	potential exposure	fire, release of toxic and ecotoxic substances
VULNERABLE OBJECTS	people threatened in high risk zones	Muttenz area
	people that might be affected	Basle city
	environmental impacts (recipients)	10.000 m^3 fire water containing about 30 metric tonnes of the chemical stored in the warehouse drained to the Rhine
	impact on property	damage to storage buildings
	areas affected by the incident (source distance)	severe damage to the Rhine over a length of about 250 km
SCENARIO	incident mechanisms	not known
	initiating events/upsets	-
	external events	-
	event sequences (intermediate events)	fire discovered and fire alarm raised
	escalation - domino effects	danger of fire spreading to neighbouring storages
	duration of event sequences	31 October 1986: *13.00* last employee left storage. *22.05 - 22.08* Sandoz safety guard checked storage. 1 November 1986: *00.19* alarm raised by police patrol and Sandoz safety personnel. *00.22* fire brigade chief arrives. *00.25* major emergency declared. *00.30* fire brigade arrives. *00.45* approx. 200 men from 10 fire brigades in action. *04.30* fire under control. *?* chemical alarm raised in Basle and a number of communities in the area with air raid sirens, radio, police car loudspeakers. *07.00* all-clear signal given.
	systems response to events/upsets	contingency systems detection, alarms, emergency response procedures mitigating systems sprinklers, catch basins
	operator response to events/upsets	emergency response procedures sufficient knowledge to understand the situation and initiate adequate response
	substances formed during the incident	fumes of phosphoric esters, mercaptanes
EMERGENCY SUPPORT	basic ways of controlling/fighting the UFOE(s)	cover with foam, fire fighting
	emergency organisations	Sandoz fire brigade (Muttenz and Basle), Ciba-Geigy fire brigade and other neighbouring plant fire brigades, harbour fire brigade, Muttenz fire brigade
	special equipment	breathing apparatus, heat protective clothing
	mitigation systems	none
	escape routes	-
	alarms	Sandoz safety personnel contacts internal and external fire brigades
	inventories	during night-time the Sandoz safety personnel

CONTEXT (II)		STORAGE Fire at warehouse 956 at the Muttenz Works Sandoz, Basle, Switzerland, 1 November 1986
EMERGENCY SUPPORT (continued)	communication lines	Sandoz safety personnel → internal fire brigade → external fire brigades → authorities → public
	lines of command	-
	requirements to personnel qualification	knowledge of plant layout, contents in warehouse, contents of neighbouring warehouses
	contacts to experts	chemical experts, toxicologists, ecologists
	possibilities for an efficient emergency control	fire out of control. The emergency operation concentrated on preventing the fire from spreading to other buildings

TRAINING		STORAGE Fire at warehouse 956 at the Muttenz Works Sandoz, Basle, Switzerland, 1 November 1986
TRAINING OBJECTIVES	time aspects for on-site operations	large amounts of flammable compounds caused rapid development of the fire
	priority of decisions and actions	-
	critical conditions	-
	constraints on access to incident location	heat radiation
	early warning of people	radio, TV, police
	evacuation (transport of injured persons)	ambulance services and other means for transportation
	measures for environmental protection	collection of fire fighting water
	operations by internal emergency organisation	detection and initial fire fighting, call for further assistance, information to authorities and public
	operations by external emergency organisations	co-ordination of emergency operation, including hospitals and experts
	fields of responsibilities	-
	communication with the public	air raid sirens, radio, police car loudspeakers. Inadequate information to the public and to neighbouring countries, public reaction to the accident, public quest for information
	co-operation between organisations	-
PARTICIPANTS	trainees	-
	supervisors	-
	evaluators	-
DATA ACQUISITION	logging	-
	observations	-

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APPENDIX C

Power plant - nuclear

Accidents

Athens - fire at nuclear plant (1975, Alabama, USA)
Chernobyl - accident at reactor (1986, Ukraine, Russia)
Three Mile Island - accident at reactor (1979, Penn., USA)
Leningrad - fuel channel rupture (1992, Russia)

STATUS (I)		POWER PLANT - NUCLEAR
TERRITORY CHARACTERISTICS	area (e.g. urban, industrial, rural)	urban or industrial
	population density	medium⇨ high, industries close to the plant
	dispersion routes	puffs and plumes by air (combustion products, gaseous releases) heavy gases by air (gaseous releases) liquids by sewer system to public waste water treatment plant liquids to soil (subsoil water) liquids to marine recipients (e.g. streams, lakes, rivers)
	meteorological and topographical factors	predominant wind directions - long distances predominant weather conditions (rain) - long distances atmosphere stability - long distances ! surface roughness plant layout, neighbours (e.g. companies), infrastructure, topographical conditions
RESOURCES	personnel directly involved in the activity	plant staff
	technical configuration	reactors, generators, storages, utility systems
	amount and number of chemical substances	normally very few in number but large quantities, chemicals well-known by the plant personnel: e.g. enriched uranium dioxide, zirconium alloy graphite, boron carbide aluminium, helium-nitrogen mixture
	construction materials	steel, plastics (PVC), insulating materials, concrete, zirconium alloy etc.
	electrical supply system	own supply system, emergency diesel generators, public supply system
	communication system	e-mail, phone, fax, internal paging system
	transport system	internal transport system (truck, lorry, pipelines), heavy fuel containers
PROCESS CONDITION	energy potential	large amount of radioactive fuel will be present, dynamics of decay heat rates
	temperature, high/low	medium temperatures (T<400°C)
	pressure, high/low	low/medium (≈ 150 bar)
SYSTEMS CONTROL	automation	high on reactor operations (control and protection systems, emergency reactor protection systems), low on storages
	instrumentation	normally high degree of instrumentation (alarms, process conditions) on reactor processes, low on storages
	on-line control	high degree on reactor operations, low on storages
	process control	registration and regulation of reactor process parameters (pressure, coolant flow rate, temperature, concentration, level, fuel channel power, containment pressure, radiation level)
	operator supervision	control room supervision
	safety systems, confinements	containment, process equipment, control system, alarms

STATUS (II)		POWER PLANT - NUCLEAR
ORGANISATION	work organisation	strategic level: station directors (managing, technical etc.) tactical level: head of departments (production, maintenance, environment etc.) operation level: operator, officer in charge, plant shift foreman, managing engineers
	safety organisation	emergency director safety officer safety, health and welfare committees safety groups auditing and control by authorities
SOURCES OF INFORMATION	system documentation	technical configuration of the plant, PI diagrams, flow charts, process descriptions, maintenance, logs of reactor operation data, redundancy principles, construction of containment systems, procedures, instructions, safety systems, internal emergency plans, probabilistic safety assessment (PSA)
	literature	information about radiation, component reliability data, theories on redundancy, containment systems, probabilistic safety assessment (PSA)
	accident descriptions	accident/incident/near misses occurred at the plant or at similar plants, operational reliability data, ASAR reports (As operated Safety Analysis Reports)
	information from organisations/consultants	specific analyses and investigations (risk analysis, health hazards, environmental hazards)
	information from authorities	external emergency plans, legislative requirements and approvals, safety cases submitted to the authorities, auditing programmes and results
	validation of information and sources	information up to date, information available
ANALYSIS METHODS	structural aspects	plant design, plant layout, component reliability, process conditions, process parameters, redundancy, containment (structural reliability), moderator in reactor, ergonomic design and layout of control room interfaces
	operational aspects	human reliability assessment of procedural tasks, response of operators on alarms, interpretation of instrument reading, qualification of personnel
	managerial aspects	fields of responsibility, information channels, safety culture, safety rules, attitudes, working discipline, resource allocation, decision-making hierarchy, interaction with other socio-technical systems (e.g. authorities, organisations), public relations

CONTEXT (I)		POWER PLANT - NUCLEAR
INCIDENT	hazard source	radioactive substances, reaction energy, radiation, contamination
	loss of confinement	damage to containment, rupture of process equipment
	uncontrolled flow of energy	nuclear energy
	potential exposure	release of radioactive substances, thermal explosion, radiation, contamination
VULNERABLE OBJECTS	people threatened in high risk zones	personnel, neighbours, passers-by, people staying in the vicinity, the high risk zone may of large extension, the exposure may cause long-term or chronic effects on human beings
	people that might be affected	people living in neighbour regions and countries
	environmental impacts (recipients)	threatened recipients close to the plant will be known by the plant personnel and the authorities, contamination of soil (vegetables, dairy products) the exposure may cause long-term or chronic effects on the environment.
	impact on property	damage to power plant, damage to neighbour buildings, damage to infrastructure
	areas affected by the incident (source distance)	normally max. 1- 500 km from the source, may be larger
SCENARIO	incident mechanisms	equipment malfunction, containment failure, human error, loss of coolant, external event, leakage, rupture of fuel channels, reactor run-away etc.
	initiating events/upsets	equipment malfunction, human error, inadequate/wrong response from operators or safety systems, loss of coolant, deviation from procedures
	external events	e.g. traffic problems, insufficient knowledge about the incident, escalation of the incident course, bad weather conditions, public response, volunteer/mandatory evacuation, means for transport for a large number of evacuees
	event sequences (intermediate events)	safe plant state ⇨ plant in disturbed state ⇨ plant in hazardous condition (e.g. loss of coolant, temperature increase, heat transfer crises) ⇨ dangerous disturbance to plant (e.g. fuel channel rupture) ⇨ release ⇨ harm⇨ emergency operation
	escalation - domino effects	escalation possible to other plant units/reactors or neighbours, core meltdown
	duration of event sequences	typically hours - may be short - from the initiating event until the radioactive substances are released
	systems response to events/upsets	safety system response: relief valves, utilities, components, automatic shut down systems mitigation system response: vents, dikes, sprinklers, containment/building, ventilation system, radioactive waste tanks, fire extinguishers, ventilation filters; contingency system response: detection, alarms, procedures, safety rules
	operator response to events/upsets	planned/ad hoc operations, sufficient knowledge and training to understand the situation and initiate ad hoc response, personnel safety equipment

CONTEXT (II)		POWER PLANT - NUCLEAR
SCENARIO (continued)	substances formed during the incident	few (radioactive aerosols, radioactive particles, radioactive noble gasses, iodine)
EMERGENCY SUPPORT	basic ways of controlling/fighting the UFOE(s)	cover leak, reduce source, evacuate, stop traffic to area, first aid
	emergency organisations	planned/dedicated, internal and external organisations
	special equipment	e.g. monitors, personnel protection (respirators, clothing), emergency treatment of people exposed to radioactive materials, shielding equipment, decontaminating chemicals, KI-tablets
	mitigation systems	e.g. reactor building, CO_2 total flooding system, collection of water from fire fighting, mixture of boron, sand, clay and lead to be dropped by helicopter
	escape routes	normally described in the internal emergency plan
	alarms	local warning and emergency systems (the plant unit) internal warning and emergency systems (the company area) external warning and emergency (neighbours, authorities)
	inventories	number of people employed, head on duty, amount of radioactive substances at the plant, plant layout
	communication lines	contacts to leader of the emergency operation, contact to head on duty, contact to hospitals, contact between police and fire brigade
	lines of command	head of emergency operation, orders to fire brigade/police/ambulance/hospitals
	requirements to personnel qualification	knowledge about radiation, contamination, fire fighting, radiation protective measures
	contacts to experts	reactor engineers, health physicists, doctors, meteorological experts, logistic personnel
	possibilities for an efficient emergency control	primary victims can be difficult to rescue, accident escalation can be avoided if the emergency forces are on-site within ½ hour

TRAINING (I)		POWER PLANT - NUCLEAR
TRAINING OBJECTIVES	time aspects for on-site operations	a fast establishment of an on-site emergency operation is normally needed, the emergency organisations must be at the incident location less than ½ hour after the incident has occurred
	priority of decisions and actions	evacuate, reduce source, first aid, monitoring radiation levels
	critical conditions	substances and materials involved, amount of substances and materials, loss of control features, temperatures, pressures, flow
	constraints on access to incident location	emergency situations are normally taken into account in the plant layout, missiles from an explosion can block emergency and escape routes, areas and rooms can be inaccessible due to high levels of radiation

TRAINING (II)		POWER PLANT - NUCLEAR
TRAINING OBJECTIVES (continued)	early warning of people	internal emergency organisation, police (radio, TV, newsletters, posters)
	evacuation (transport of injured persons)	evacuation of people in high risk zones, transportation of injuries to hospital the accident course may develop fast and a fast evacuation is needed, evacuation plans must be available taken into account the demographically factors (schools, hospitals, sport centre etc.)
	measures for environmental protection	knowledge about radioactive substances, dispersion routes, meteorological conditions, mitigating measures, measuring facilities, personnel resources
	operations by internal emergency organisation	early detection of an incident, fast call for an emergency, first aid, mitigation measures
	operations by external emergency organisations	communication, co-operation, co-ordination of emergency efforts, mitigation measures, evacuation, provision of special equipment, radiological monitoring teams
	fields of responsibilities	normally the head of the fire brigade is head of the external emergency operation, head on duty responsible for internal operations before the external operations are put into force primary emergency operations by the internal emergency organisation, transferring the responsibility from the internal to the external emergency organisation, subsequent emergency operations by the external emergency organisations, co-ordination between different external emergency response organisations at state and federal level
	communication with the public	information about injuries and environmental impact information to relatives, neighbours, authorities, availability to practical material about radioactivity, emergency news spots, press conferences
	co-operation between organisations	fire brigade, police, plant staff, hospital, authorities, ambulance service, means for communication between internal and external emergency organisations, between external emergency organisations (fire brigade, police, hospitals, ambulance service), national and international emergency measures and organisations, means for communication
PARTICIPANTS	trainees	plant safety officer, plant managers/engineers, heads of external emergency organisations, health physicists, key decision makers
	supervisors	external or internal experts
	evaluators	representatives from the company, the authorities, the emergency organisations, training experts
DATA ACQUISITION	logging	computer logs, video/audio tape recordings
	observations	working climate, stress factors

STATUS (I)		POWER PLANT - NUCLEAR Fire at Browns Ferry Nuclear Plant Athens, Alabama, USA, 22 March 1975
TERRITORY CHARACTERISTICS	area (e.g. urban, industrial, rural)	Industrial.
	population density	-
	dispersion routes	Air, water (Tennessee River).
	meteorological and topographical factors	-
RESOURCES	personnel directly involved in the activity	A few workers in the cable spreading room and operators in the control room.
	technical configuration	The cable spreading room was used for cables to two reactor units.
	amount and number of chemical substances	PVC, polyethylene, nylon cables. Polyurethane, flamematic 71A.
	construction materials	Concrete, cable trays (metal).
	electrical supply system	-
	communication system	Telephone.
	transport system	-
PROCESS CONDITION	energy potential	-
	temperature, high/low	-
	pressure, high/low	-
SYSTEMS CONTROL	automation	No automatic or manual fixed fire protection systems.
	instrumentation	-
	on-line control	-
	process control	-
	operator supervision	-
	safety systems, confinements	Reactor building (containment), process equipment, control system.
ORGANISATION	work organisation	Engineer on duty, operator, workers.
	safety organisation	Safety officer, fire men (internal).
SOURCES OF INFORMATION	system documentation	-
	literature	-
	accident descriptions	-
	information from organisations/consultants	-
	information from authorities	-
	validation of information and sources	-
ANALYSIS METHODS	structural aspects	The construction of the cable spreading room allowed fire to spread between two reactor units. A candle was used to detect leaks (draught) in the concrete wall between the cable spreading room and the reactor building.
	operational aspects	Open fire can ignite construction materials
	managerial aspects	No fire guard was placed on the other side of the wall to detect the fire and begin fire fighting. Adequate methods to detect leaks were not developed/enforced.

CONTEXT (I)		**POWER PLANT - NUCLEAR** Fire at Browns Ferry Nuclear Plant Athens, Alabama, USA, 22 March 1975
INCIDENT	hazard source	Fire damaged cables ⇒ loss of reactor control. Release and contamination of environment.
	loss of confinement	Fire and subsequent loss of reactor control.
	uncontrolled flow of energy	Nuclear energy.
	potential exposure	Radiation, release of radioactive substances.
VULNERABLE OBJECTS	people threatened in high risk zones	Personnel in the cable spreading room and control room.
	people that might be affected	Plant personnel, people outside the power plant.
	environmental impacts (recipients)	Toxic fumes released to air.
	impact on property	Harm to materials and property.
	areas affected by the incident (source distance)	Internal.
SCENARIO	incident mechanisms	Fire in cable trays under the control room.
	initiating events/upsets	Unorthodox operation.
	external events	-
	event sequences (intermediate events)	Test of leak tightness between cable spreading room and reactor 1 with candle ⇒ flame sucked into opening ⇒ ignition of polyurethane ⇒ fire extinguishers unable to control fire ⇒ Cardox total flooding system (CO_2) slows down the fire ⇒ fire in the reactor building ⇒ 5 1/2 hrs. later water hoses were used ⇒ fire under control.
	escalation - domino effects	Danger of a nuclear incident. as the fire should initiate a safe shutdown of the two reactor units.
	duration of event sequences	*12.35*: Fire started in cable spreading room. *12.40*: Fire alarm called in. *12.51*: Unit one reactor scrammed. *12.55*: Public Safety Service fire truck arrived. *13.02*: Unit two reactor scrammed. *13.09*: Athens Fire Department notified. *13.20 - 13.30*: Cardox total flooding system discharged. *13.25:* Athens Fire Department arrived with one truck. *13.30 - 14.00*: Self-contained breathing apparatus required in control room. *14.30 - 15.00*: Cardox total flooding system. *14.00 - 16.00*: Cable fire in reactor building burning unhampered. Fire fighters effort abandoned in order to shut down units one and two. *15.00 - 16.00*: Cardox total flooding system again. *18.00*: Hose stream first used. *18.45*: Fire considered out.
	systems response to events/upsets	Safety systems: emergency shut down. Mitigating systems: fire extinguishers, fire hoses, sprinklers. Contingency systems: fire/smoke detectors, alarms, procedures.
	operator response to events/upsets	Planned/ad hoc emergency operations. Personnel safety equipment.
	substances formed during the incident	Heat, smoke (CO, CO_2, HCl).
EMERGENCY SUPPORT	basic ways of controlling/fighting the UFOE(s)	Evacuate, cover leaks, limit source, first aid.
	emergency organisations	Internal and external fire fighting groups.

CONTEXT (II)		POWER PLANT - NUCLEAR Fire at Browns Ferry Nuclear Plant Athens, Alabama, USA, 22 March 1975
EMERGENCY SUPPORT (continued)	special equipment	Self-contained breathing apparatus.
	mitigation systems	Fire extinguishers, cardox total flooding system, fire hoses.
	escape routes	-
	alarms	-
	inventories	-
	communication lines	-
	lines of command	-
	requirements to personnel qualification	Knowledge about fire fighting in electric cables.
	contacts to experts	Fire fighting experts, reactor experts, plant design and layout.
	possibilities for an efficient emergency control	Fire fighting commenced immediately. Fire fighting techniques/criteria for fire in electric cables not followed.

TRAINING		POWER PLANT - NUCLEAR Fire at Browns Ferry Nuclear Plant Athens, Alabama, USA, 22 March 1975
TRAINING OBJECTIVES	time aspects for on-site operations	A fast control of the fire is essential.
	priority of decisions and actions	-
	critical conditions	Loss of control features.
	constraints on access to incident location	The design and layout of the cable spreading room prevented an efficient emergency operation.
	early warning of people	-
	evacuation (transport of injured persons)	-
	measures for environmental protection	-
	operations by internal emergency organisation	Early detection of an incident, fast call for emergency support, mitigating measures, exercises involving external emergency organisation.
	operations by external emergency organisations	Mitigating measures, communication, co-operation, evacuation of injuries, exercises involving internal emergency organisation.
	fields of responsibilities	Internal emergency organisation → external emergency organisation.
	communication with the public	-
	co-operation between organisations	Internal fire fighters → external fire fighters in charge of operation.
PARTICIPANTS	trainees	-
	supervisors	-
	evaluators	-
DATA ACQUISITION	logging	-
	observations	-

Reference "Fire at Browns Ferry Nuclear Plant, Athens, Alabama, USA, 22 March 1975":

The Nuclear Liability and Property Insurance Association, TVA's Browns Ferry Nuclear Plant, Athens, Alabama, May 1975.

STATUS (I)		POWER PLANT - NUCLEAR Accident at the Chernobyl Nuclear Power Plant Ukraine, Russia, 26 April 1986
TERRITORY CHARACTERISTICS	area (e.g. urban, industrial, rural)	Industrial, city.
	population density	Pripyat: 45.000 inhabitants < 3 km from the NPP (Nuclear Power Plant). Chernobyl: 12.500 inhabitants 15 km south-east of the NPP. Kiev: 2,5 million inhabitants 130 km south of the NPP. Minsk: 1,3 million inhabitants 320 km north-east of the NPP.
	dispersion routes	Air. Water, the river Pripyat, a tributary to the Dnieper.
	meteorological and topographical factors	Wind direction changing from north-east → east → south-east.
RESOURCES	personnel directly involved in the activity	176 operational staff. 268 builders and assemblers working on construction of additional units.
	technical configuration	4 RBMK 1000 nuclear reactor units each producing 1000 MW electrical power (8 x 500 MW generators), 3200 MW thermal power. The plant was designed to have twin reactors, with two independent reactor systems with a number of interchangeable auxiliary systems in a machine room.
	amount and number of chemical substances	2% enriched uranium dioxide fuel elements ≅ 60.000. Zirconium alloy (cladding). Graphite (moderator) 2500 tons. Boron carbide aluminium (211 control rods). Helium-nitrogen mixture.
	construction materials	Zirconium alloy. Concrete. Steel
	electrical supply system	Internal. Diesel emergency generators.
	communication system	-
	transport system	-
PROCESS CONDITION	energy potential	High (nuclear fuel).
	temperature, high/low	Medium.
	pressure, high/low	Medium.
SYSTEMS CONTROL	automation	No automatic reactor trip mechanism, possibility to override alarms.
	instrumentation	High.
	on-line control	High.
	process control	Registration of reactor parameters: temperature, pressure, flow, level.
	operator supervision	Control room supervision.
	safety systems, confinements	Reactor unit, control system, auxiliary process equipment.
ORGANISATION	work organisation	Strategic level: station director. Tactical level: - Operation level: officer in charge, plant shift foreman, operators.
	safety organisation	Security officer, operators, internal emergency organisation.

STATUS (II)		**POWER PLANT - NUCLEAR** Accident at the Chernobyl Nuclear Power Plant Ukraine, Russia, 26 April 1986
SOURCES OF INFORMATION	system documentation	Plant instructions, logs of reactor operation data, internal emergency plan (5-10 persons on each shift).
	literature	No literature available to the public about radiation.
	accident descriptions	-
	information from organisations/consultants	-
	information from authorities	External emergency plans involving the fire fighting brigades in Pripyat and Chernobyl, hospitals in Pripyat and Kiev, exercises on site (not major emergencies).
	validation of information and sources	-
ANALYSIS METHODS	structural aspects	No containment building, short on good control systems, only operator operated emergency control rods, excess of moderator in reactor .
	operational aspects	Response of operators on alarms, overriding alarms.
	managerial aspects	Inadequate safety rules, station personnel could independently carry out actions not sanctioned by professionals, limited attention to state of instruments between planned preventive maintenance.

CONTEXT (I)		**POWER PLANT - NUCLEAR** Accident at the Chernobyl Nuclear Power Plant Ukraine, Russia, 26 April 1986
INCIDENT	hazard source	Nuclear reactor, release of radioactive materials to air, water, soil.
	loss of confinement	Rupture of reactor unit.
	uncontrolled flow of energy	Nuclear energy.
	potential exposure	Reactor runaway, thermal explosion, release of radioactive substances.
VULNERABLE OBJECTS	people threatened in high risk zones	Personnel, inhabitants in Pripyat .
	people that might be affected	People in Ukraine, White Russia, Europe.
	environmental impacts (recipients)	The river Pripyat and the river Dnieper, radioactive particles released to the air.
	impact on property	Reactor and reactor building damaged.
	areas affected by the incident (source distance)	NPP area, Pripyat, Chernobyl. 30 km safety zone. Radioactivity measured in several other countries.
SCENARIO	incident mechanisms	Procedures not followed and alarms overruled ⇒ reactor instability ⇒ explosion.
	initiating events/upsets	Equipment malfunction, control systems disconnected, deviation from procedures, loss of coolant.
	external events	Traffic problems, means of transport for a large number of evacuees, rehousing facilities.

CONTEXT (II)		POWER PLANT - NUCLEAR Accident at the Chernobyl Nuclear Power Plant Ukraine, Russia, 26 April 1986
SCENARIO (continued)	event sequences (intermediate events)	Test program initiated/power reduction, emergency core cooling system disconnected ⇒ unplanned delay ⇒ test program resumed after 9 hours ⇒ control rods not reset ⇒ thermal power fell to 30 MW and reactor poisoned with xenon-135, later stabilised at 200 MW (required for the experiment 700-1000 MW) ⇒ additional circulating coolant pumps switched on to provide reliable cooling during the experiment ⇒ reduction of steam production ⇒ low level in steam drums ⇒ feedwater pumps used to increase the water level, trip signals overridden ⇒ cold water to the reactor ⇒ steam pressure falls further ⇒ additional control rods withdrawn from the core (6-8 control rods in the core, design requires a minimum of 15, total 211) ⇒ safety rules requires a shut down, overruled ⇒ automatic trip system disengaged (not included in experiment schedule) ⇒ experiment started, steam lines to turbine generator closed ⇒ reactor power steep rise ⇒ full emergency shutdown ordered ⇒ not all control rods reached their lower position ⇒ heat transfer crisis ⇒ fuel channel rupture ⇒ thermal explosion.
	escalation - domino effects	Possibility for fire to escalate into reactor unit 3 from the machine hall through cable tunnels.
	duration of event sequences	25 April 1986: *01.00* start-up of power reduction. *13.05* reactor at 50%. *14.00* request to remain on-line. *23.10* reduction resumed. 26 April 1986: *00.28* 30 MW thermal power. *01.00* reactor stabilised at 200 MW. *01.23.04* experiment started. *01.23.40* reactor power steep rise. *01.23.48* thermal explosion.
	systems response to events/upsets	Safety system: relief valves, utilities, computer controlled control systems, automatic shut down systems. Mitigating system: containment building, ventilation. Contingency system: detection, alarms, procedures, safety rules.
	operator response to events/upsets	Planned/ad hoc operations. Personnel safety equipment. Safety equipment.
	substances formed during the incident	Radioactive aerosols (cesium-137, iodine-131, neptunium, plutonium (239+240) strontium-90, zirconium-95), heat from fire.
EMERGENCY SUPPORT	basic ways of controlling/fighting the UFOE(s)	Evacuate, reduce source, cover leak.

CONTEXT (III)		**POWER PLANT - NUCLEAR** Accident at the Chernobyl Nuclear Power Plant Ukraine, Russia, 26 April 1986
EMERGENCY SUPPORT (continued)	emergency organisations	Moscow emergency centre, government commission operational group (scientists, specialists, officials) sent to Chernobyl to be in charge of the emergency operation. Internal fire fighting. External fire fighting brigades from Pripyat and Chernobyl. Regional hospitals, specialised medical teams. Military. Monitoring teams.
	special equipment	Protective respirators. Protective clothing. Radiation monitoring instruments. Decontaminating chemicals. KI (iodine) tablets.
	mitigation systems	ca. 5.000 tonnes of boron, dolomite, sand, clay and lead dropped by helicopter.
	escape routes	Internal - Evacuation of inhabitants in Pripyat: busses, trucks and private cars. The railway station was to contaminated to be used.
	alarms	Automatic fire alarm at the fire brigade in Pripyat.
	inventories	-
	communication lines	Contact to fire brigade, hospitals, emergency centre (central authorities).
	lines of command	-
	requirements to personnel qualification	Knowledge about radiation, fire fighting.
	contacts to experts	On-site personnel (engineers, health physicists). Scientists, medical experts, logistic personnel.
	possibilities for an efficient emergency control	The primary on-site concern was the fire and not the radiation danger. Lack of necessary quantity of protective respirators and basic hygiene equipment.

TRAINING (I)		**POWER PLANT - NUCLEAR** Accident at the Chernobyl Nuclear Power Plant Ukraine, Russia, 26 April 1986
TRAINING OBJECTIVES	time aspects for on-site operations	Fast operation is critical to prevent fire from escalating to other parts of the plant.
	priority of decisions and actions	Cover leak, evacuate, first aid, reduce source, clean contaminated area.
	critical conditions	Flow, temperature, pressure, substances involved.
	constraints on access to incident location	Parts from the explosion can block emergency routes.
	early warning of people	Internal/external emergency organisation, police, radio, TV, newsletters, posters.
	evacuation (transport of injured persons)	135.000 persons were evacuated from a 30 km safety zone. List of evacuees, evacuation routes, means of transportation, rehousing.
	measures for environmental protection	Knowledge about radioactive materials, mitigating measures, dispersion routes, meteorological conditions, measuring facilities.

TRAINING (II)		POWER PLANT - NUCLEAR Accident at the Chernobyl Nuclear Power Plant Ukraine, Russia, 26 April 1986
TRAINING OBJECTIVES (continued)	operations by internal emergency organisation	Early detection of an incident (safety awareness), first aid, call for assistance, mitigating measures.
	operations by external emergency organisations	Co-ordination of emergency efforts, communication, mitigating measures, evacuation, provision of special equipment.
	fields of responsibilities	Internal emergency personnel → fire brigade in Pripyat and Chernobyl → operational group.
	communication with the public	Mitia forces, word of mouth, posting notices.
	co-operation between organisations	Co-ordinated by the operational group.
PARTICIPANTS	trainees	-
	supervisors	-
	evaluators	-
DATA ACQUISITION	logging	-
	observations	-

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STATUS (I)		POWER PLANT - NUCLEAR Three Mile Island Unit 2 Reactor Pennsylvania, USA, 28 March 1979
TERRITORY CHARACTERISTICS	area (e.g. urban, industrial, rural)	Urban: Close to Goldsboro and Middletown, 16 km south-east of Harrisburg
	population density	>135.000 persons
	dispersion routes	Air, water the Susquehanna River
	meteorological and topographical factors	Near windless, changing directions
RESOURCES	personnel directly involved in the activity	1 shift supervisor; 1 shift foreman; 2 control room operators; 6 auxiliary operators Later a total of 23 (or ≈ 50) key plant personnel were involved in unit 2 operations during the accident
	technical configuration	Two independent 959 MW pressurised water reactors
	amount and number of chemical substances	2,57% enriched uranium dioxide fuel elements (36.816) Zirconium alloy (cladding) Boron and silver control rods
	construction materials	Carbon steel; Concrete
	electrical supply system	Internal: External Emergency diesel generators
	communication system	Telephone Internal paging system
	transport system	-
PROCESS CONDITION	energy potential	Decay heat immediately after shutdown: 160 MW Decay heat after 1 hour: 33 MW Decay heat after 10 hours: 15 MW and decreasing more slowly
	temperature, high/low	Primary coolant circuit outlet temperature ≈ 320 °C.
	pressure, high/low	Primary coolant circuit ≈ 150 bar.
SYSTEMS CONTROL	automation	High
	instrumentation	High
	on-line control	High
	process control	Recording of process parameters and other parameters i.e. containment pressure, radiation level
	operator supervision	Control room supervision
	safety systems, confinements	Reactor building (containment)
ORGANISATION	work organisation	Strategic level: Station manager and utility headquarters in Reading Tactical level: Unit 2 superintendent Operational level: Supervisor, operations; technical support; shift supervisors; shift foreman; control room operators; auxiliary operators
	safety organisation	Emergency director, emergency command team
SOURCES OF INFORMATION	system documentation	Plant instructions, emergency response plans
	literature	-
	accident descriptions	A similar incident at Davis Besse Nuclear Power Plant 24 September 1977, but the analysis of the incident investigation were not passed on to TMI

STATUS (II)		POWER PLANT - NUCLEAR Three Mile Island Unit 2 Reactor Pennsylvania, USA, 28 March 1979
SOURCES OF INFORMATION (continued)	information from organisations/consultants	-
	information from authorities	Local emergency plans including evacuation plans were not available and not required by the Federal Nuclear Regulatory Commission. County plans included a 10 km evacuation zone. No/limited co-ordination between local authorities and county authorities
	validation of information and sources	-
ANALYSIS METHODS	structural aspects	Pilot-operated relief valves are known to fail open The design and layout of the control room makes reading of certain instruments difficult/impossible
	operational aspects	Not following maintenance procedures, leaving valves in wrong position Not reading positions of valves in the control room and subsequently correct positions Misinterpreting/ignoring instrument readings
	managerial aspects	An attitude at NRC and plant level that the engineered design safeguards built into the plant were more than adequate, and that an accident could not occur Procedures included major loss of coolant accidents, but not minor loss of coolant accidents ⇒ inadequate operator training. Operators not encouraged to make their own assumptions of the situation

CONTEXT (I)		POWER PLANT - NUCLEAR Three Mile Island Unit 2 Reactor Pennsylvania, USA, 28 March 1979
INCIDENT	hazard source	Release of radioactive materials to air and water
	loss of confinement	Containment damage
	uncontrolled flow of energy	Nuclear energy
	potential exposure	Radiation, release of radioactive substances
VULNERABLE OBJECTS	people threatened in high risk zones	On site. Control room personnel were required to wear respirators during some periods
	people that might be affected	People in Pennsylvania and neighbouring states
	environmental impacts (recipients)	Air, soil (vegetables, dairy products), the Susquehanna River
	impact on property	-
	areas affected by the incident (source distance)	People in zones up to 50 km were considered at risk People in a radius of 100 km (10 km) from the plant received 1% (10%) of the annual background radiation during the accident

CONTEXT (II)		POWER PLANT - NUCLEAR Three Mile Island Unit 2 Reactor Pennsylvania, USA, 28 March 1979
SCENARIO	incident mechanisms	Emergency feedwater block valves left in wrong position + incident mechanisms not included in operating manuals ⇒ operators not familiar with the failure mechanisms ⇒ correct corrective actions not taken immediately
	initiating events/upsets	Equipment malfunction, inadequate/wrong response from operators and/or safety systems
	external events	Weather conditions, public reaction to the accident, public quest for information, traffic problems, volunteer/mandatory evacuation, means for transportation, rehousing and feeding facilities
	event sequences (intermediate events)	Water in instrument air line ⇒ trip of main feedwater pumps. Block valves in emergency feedwater line in closed position (later opened) ⇒ loss of main feedwater coolant ⇒ pressure increase in reactor coolant system ⇒ pilot-operated relief valve (PORV) on the pressuriser opens. Further pressure increase ⇒ reactor automatically shuts down. The PORV fails open. Operators fail to recognise this and subsequently to close the PORV block valve ⇒ loss of coolant through open PORV (radioactivity leaks into containment and auxiliary buildings) ⇒ low pressure in the reactor coolant system ⇒ steam bubble voids in the reactor coolant system ⇒ reactor coolant pumps shut down ⇒ reactor boils partly dry ⇒ core damage, cladding oxidised, hydrogen formed (vented to the containment building ⇒ combustion of hydrogen gas. Later a hydrogen recombiner is installed). PORV block valve closed and reactor coolant pump(s) restarted ⇒ reasonably stable conditions.
	escalation - domino effects	Core meltdown T ≈ 2200 °C, not recognised during the accident
	duration of event sequences	28 March 1979: 04.00 Trip of main feedwater pumps and subsequently turbine and generator. + 3 sec. PORV opens, + 8 sec. Reactor automatically shuts down, + 13 sec. PORV fails to close; 04.08 Block valves in emergency feedwater line opened; 04.19 Radiation alarm, release to environment through auxiliary stack; 04.30 Steam bubble voids in reactor cooling system; 05.41 All reactor coolant pumps shut down (core uncovered); 06.18 PORV isolated by closing a block valve;13.50 Hydrogen combustion in containment building; 19.50 One reactor coolant pump restarted. 29 March 1979: Release of radioactivity to the Susqueanna River. 30 March 1979: Uncontrolled puff release of radioactivity 31 March 1979: Decay power 7,4 MW. 2 April 1979: Hydrogen recombiner in service. Calculated hydrogen bubble size: 15-25 m^3. 27 April 1979: All cooling pumps stopped and natural circulation established.

CONTEXT (III)		POWER PLANT - NUCLEAR Three Mile Island Unit 2 Reactor Pennsylvania, USA, 28 March 1979
SCENARIO (continued)	systems response to events/upsets	Safety systems relief valves, emergency pumps and lines, other emergency equipment, computer controlled control systems, emergency shutdown systems Mitigating systems containment, ventilation filters, radioactive waste tanks Contingency systems detection, alarms, emergency response procedures and rules
	operator response to events/upsets	Planned operations/emergency response procedures Sufficient knowledge and training to understand the situation and initiate ad hoc response
	substances formed during the incident	Radioactive gasses xenon and hydrogen: 2,4 - 13 million curie released (calculated) Radioactive iodine: 13- 17 curie released (calculated)
EMERGENCY SUPPORT	basic ways of controlling/fighting the UFOE(s)	Evacuate, cover leak, limit source, first aid
	emergency organisations	Pennsylvania Emergency Management Agency (Civil Defence); Federal Nuclear Regulation Commission (NRC); NRC Incident Response Centre; State Bureau of Radiation Protection; State police; National guard
	special equipment	Protective respirators; Protective clothing; Radiation measuring instruments; Decontaminating chemicals
	mitigation systems	Reactor building (containment); Waste gas decay tank; Radiation waste storage tank; Ventilation filters
	escape routes	-
	alarms	The plant personnel contacts the authorities when a site emergency is declared
	inventories	-
	communication lines	Nuclear power plant → NRC, PEMA, other Federal and State authorities, public
	lines of command	-
	requirements to personnel qualification	Knowledge of plant design and layout, knowledge about radiation and radiological monitoring, radiation protective measures
	contacts to experts	Nuclear engineers, health physicists, medical experts
	possibilities for an efficient emergency control	Lack of adequate operational emergency response plans No emergency response communication system with backup systems in place

TRAINING (I)		POWER PLANT - NUCLEAR Three Mile Island Unit 2 Reactor Pennsylvania, USA, 28 March 1979
TRAINING OBJECTIVES	time aspects for on-site operations	Fast response (safe/controlled shutdown) is necessary
	priority of decisions and actions	Cover leak, evacuate
	critical conditions	Core uncovered, auxiliary damaged. loss of coolant
	constraints on access to incident location	The health physicists emergency control centre and the laboratory were inaccessible due to high levels of radiation
	early warning of people	Radio and TV, police, emergency management agency, national guard
	evacuation (transport of injured persons)	Evacuation plans were not considered necessary by the NRC Evacuation was not recommended due to lack of evacuation plans and because evacuation would include hospitals and a prison
	measures for environmental protection	Knowledge about released quantity of radioactivity, measuring facilities, mitigating measures, dispersion routes, meteorological conditions (short/long range)
	operations by internal emergency organisation	Technical Support Centre. Plant management and staff from other reactors (on-site). Concentrate on broad lines, co-ordination of fire brigade, takes decisions in co-operation with the police and local authorities on evacuation, provides information to the press centre
	operations by external emergency organisations	Provide adequate emergency response plans involving the plant, hospitals, emergency management agencies, radiological monitoring teams, Nuclear Regulatory Commission
	fields of responsibilities	Transfer of co-ordinating responsibility from internal emergency response organisation to external emergency response organisation, and the co-ordination of response between different external emergency response organisations at state and federal level (Emergency Response Plan and Interagency Radiological Assistance Plan)
	communication with the public	Absence of adequate, accurate, and confirmatory information Briefers at the Technical Support Centre with sufficient background information and updated information on the accident Press conferences Emergency news spots
	co-operation between organisations	Interagency Radiological Assistance Plan was not well known to staff at federal agencies ⇒ federal response not co-ordinated State emergency command and control duties and procedures had not been clearly established Incident Response Centre with reliable and sufficient means for communication between involved organisations

TRAINING (II)		POWER PLANT - NUCLEAR Three Mile Island Unit 2 Reactor Pennsylvania, USA, 28 March 1979
PARTICIPANTS	trainees	-
	supervisors	-
	evaluators	-
DATA ACQUISITION	logging	-
	observations	-

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STATUS		POWER PLANT - NUCLEAR Fuel channel rupture Leningrad Nuc. Pow. Plant Sosnovy Bor, Russia, 24 March 1992
TERRITORY CHARACTERISTICS	area (e.g. urban, industrial, rural)	Industrial, city.
	population density	High, close to St. Petersburg.
	dispersion routes	Air, water.
	meteorological and topographical factors	Wind direction east → south-east.
RESOURCES	personnel directly involved in the activity	Operators.
	technical configuration	RBMK-reactor (Chernobyl-type) 1000 MW.
	amount and number of chemical substances	2% enriched uranium dioxide fuel elements ≅ 60.000. Zirconium alloy (cladding). Graphite (moderator) 2500 tons. Boron carbide aluminium (211 control rods). Helium-nitrogen mixture.
	construction materials	Zirconium alloy. Concrete. Steel.
	electrical supply system	Internal. Diesel emergency generators.
	communication system	Phone, fax.
	transport system	-
PROCESS CONDITION	energy potential	High.
	temperature, high/low	Medium.
	pressure, high/low	Medium.
SYSTEMS CONTROL	automation	High, control and protection systems, emergency reactor protection systems.
	instrumentation	High.
	on-line control	High.
	process control	Recording of process parameters: coolant flow rate, fuel channel power, etc.
	operator supervision	Control room supervision.
	safety systems, confinements	Control system, process equipment.
ORGANISATION	work organisation	Strategic level: station director. Tactical level: - Operation level: officer in charge, plant shift foreman, operators.
	safety organisation	Security officer, operators, internal emergency organisation.
SOURCES OF INFORMATION	system documentation	Plant instructions, logs of reactor operation data, internal emergency plan (5-10 persons on each shift).
	literature	-
	accident descriptions	Previous similar incidents on other plants.
	information from organisations/consultants	-
	information from authorities	-
	validation of information and sources	-
ANALYSIS METHODS	structural aspects	Graphite moderator ⇒ unstable reactor, fission processes continues and accelerates when coolant is lost.
	operational aspects	-
	managerial aspects	-

CONTEXT		POWER PLANT - NUCLEAR Fuel channel rupture Leningrad Nuc. Pow. Plant Sosnovy Bor, Russia, 24 March 1992
INCIDENT	hazard source	Release of radioactive materials to air/water/soil.
	loss of confinement	Rupture in a fuel channel.
	uncontrolled flow of energy	Nuclear energy.
	potential exposure	Radiation, release of radioactive substances.
VULNERABLE OBJECTS	people threatened in high risk zones	People on site and neighbours.
	people that might be affected	Sweden, Finland.
	environmental impacts (recipients)	Release of radioactive noble gasses approx. 5100 Ci.. Release of iodine-131 0,88-2,68 Ci.
	impact on property	-
	areas affected by the incident (source distance)	Areas close to the plant.
SCENARIO	incident mechanisms	Failure of fuel channel isolation valve.
	initiating events/upsets	Reactor disturbance.
	external events	.
	event sequences (intermediate events)	Loss of coolant in fuel channel ⇒ reactor scrammed + emergency cooling ⇒ rise of temperature in fuel channel to 650-800 °C ⇒ rupture of fuel channel ⇒ release of radioactive steam to the atmosphere.
	escalation - domino effects	-
	duration of event sequences	02.34.40: loss of coolant in fuel channel 52-16. 02.34.45: fast-acting emergency shutdown. 02.35.06 - 02.35.08: rise in temperature and subsequent rupture of fuel channel. 03.40: valves to atmosphere closed.
	systems response to events/upsets	Safety system: relief valves, utilities, computer controlled control systems, automatic shut down systems. Mitigating system: containment building, ventilation system. Contingency system: detection, alarms, procedures, safety rules.
	operator response to events/upsets	Planned/ad hoc operations and procedures. Personnel safety equipment. Safety equipment.
	substances formed during the incident	Radioactive noble gasses and iodine.
EMERGENCY SUPPORT	basic ways of controlling/fighting the UFOE(s)	Evacuate, cover leaks, limit source, first aid.
	emergency organisations	Authorities.
	special equipment	-
	mitigation systems	Condensation chambers and radioactivity suppression facilities for gaseous releases.
	escape routes	-
	alarms	Information via phone and fax.
	inventories	-
	communication lines	-
	lines of command	-
	requirements to personnel qualification	Knowledge about plant layout, radiation dangers.
	contacts to experts	Health physicists, reactor engineers, meteorological experts.
	possibilities for an efficient emergency control	Good.

TRAINING		POWER PLANT - NUCLEAR Fuel channel rupture Leningrad Nuc. Pow. Plant Sosnovy Bor, Russia, 24 March 1992
TRAINING OBJECTIVES	time aspects for on-site operations	Very short time to respond to the incident.
	priority of decisions and actions	Cover leak, evacuate, first aid.
	critical conditions	Flow, temperature, pressure, chemicals involved.
	constraints on access to incident location	-
	early warning of people	-
	evacuation (transport of injured persons)	-
	measures for environmental protection	-
	operations by internal emergency organisation	Early detection of an incident (safety awareness), mitigating measures, information to authorities.
	operations by external emergency organisations	Communication with plant staff, information to the public, evacuation, information to neighbouring countries.
	fields of responsibilities	Engineers on duty, operators.
	communication with the public	-
	co-operation between organisations	Between plant staff and authorities, local/national authorities and international authorities and nuclear safety organisations.
PARTICIPANTS	trainees	-
	supervisors	-
	evaluators	-
DATA ACQUISITION	logging	-
	observations	-

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APPENDIX D

Energy distribution
(pipelines, storages, reservoirs)

Accidents

North Sea - explosion off-shore platform (1988, England)
Gothenburg - propane pipeline explosion (1981, Sweden)
Bashkir - gas pipeline rupture and explosion (1989, USSR)

STATUS (I)		ENERGY DISTRIBUTION pipelines, storages, reservoirs
TERRITORY CHARACTERISTICS	area (e.g. urban, industrial, rural)	urban, industrial, rural
	population density	high → medium → low, e.g. passage by pipelines through different regions
	dispersion routes	puffs and plumes by air (combustion products, gaseous release) liquids (e.g. oil) by sewer system to public waste water treatment plant liquids (e.g. oil) to soil or subsoil water liquids (e.g. oil) to marine recipients (e.g. sea, coastal, lakes, streams)
	meteorological and topographical factors	predominant wind direction and speed predominant weather conditions surface roughness, buildings and obstructions layout of the installation and the transfer system, neighbours (e.g. schools, companies), infrastructure, topographical conditions
RESOURCES	personnel directly involved in the activity	normally less than 50, but at offshore installations about 200-300 people can be present
	technical configuration	plant units, risers, pipelines, storages, utility systems
	amount and number of chemical substances	normally only one product (e.g. natural gas, oil) present in the distribution system, large amount of product will be contained in the distribution system, storages and reservoirs
	construction materials	steel, plastics, insulating materials, concrete etc.
	electrical supply system	public supply system, own supply system at offshore installations
	communication system	e-mail, phone, fax, UHF/VHF radio
	transport system	internal transport of auxiliary substances and materials by truck or lorry
PROCESS CONDITION	energy potential	large amount of flammable/explosive substances will be present
	temperature, high/low	liquids/gases at high temperatures in separate units of the distribution system
	pressure, high/low	liquids/gases at high pressures in separate units of the distribution system
SYSTEMS CONTROL	automation	high on transfer and process operations
	instrumentation	normally high degree of instrumentation (e.g. alarms, flow and storage conditions)
	on-line control	high on transfer and process operations
	process control	registration and regulation of transfer and process operations (flow, level, pressure, temperature etc.)
	operator supervision	control room supervision, very low what concerns field supervision
	safety systems, confinements	pipeline, control system, alarms, supervision, process equipment
ORGANISATION	work organisation	operators, operation leaders, managing engineers, head of sections, director
	safety organisation	safety groups, safety officer

STATUS (II)		ENERGY DISTRIBUTION pipelines, storages, reservoirs
SOURCES OF INFORMATION	system documentation	technical configuration of the system, PI diagrams, flow charts, transfer and process descriptions, procedures, instructions, safety systems, internal and external emergency plans
	literature	e.g. information about the chemical substances, structural reliability data, component reliability data
	accident descriptions	accidents/incidents/near misses occurred at the installation or similar installations
	information from organisations/consultants	specific analysis and investigations (risk analysis, health hazard, environmental hazards)
	information from authorities	external emergency plans, legislative requirements and approvals
	validation of information and sources	information up to date, information available
ANALYSIS METHODS	structural aspects	design principles, layout and location of the installation, structural and component reliability, transfer and process conditions/parameters
	operational aspects	human reliability assessment of procedural tasks, qualification of personnel
	managerial aspects	fields of responsibility, information channels, safety culture, working discipline, resource allocation, decision-making hierarchy, public relations, interactions with other socio-technical systems (e.g. authorities, organisations)

CONTEXT (I)		ENERGY DISTRIBUTION pipelines, storages, reservoirs
INCIDENT	hazard source	hazardous materials: flammable/explosive substances hazardous conditions: high pressure
	loss of confinement	containment failure, leakage, external damage to equipment, change of pressure
	uncontrolled flow of energy (UFOE)	high temperature, pressurised liquid, chemical energy, mechanical energy, missile
	potential exposure	fire, explosion harm to humans (burns, missile, blast), harm to environment (oil pollution), harm to materials and property
VULNERABLE OBJECTS	people threatened in high risk zones	personnel, people living close to installation or the transfer system, passers-by (mostly people who beforehand can receive information about the hazards, alarms and emergency plans)
	people that might be affected	people staying in the vicinity
	environmental impacts (recipients)	threatened recipients will be known by the personnel and the authorities, for transfer systems, e.g. pipelines, the accident location will not be known but the possible areas will be known
	impact on property	damage/destruction to property, loss of materials

CONTEXT (II)		**ENERGY DISTRIBUTION** **pipelines, storages, reservoirs**
VULNERABLE OBJECTS (continued)	areas affected by the incident (source distance)	fire or explosion accidents will normally affect areas up to max. 1 km from the source release of oil to marine recipients may affect areas far away from the source
SCENARIO	incident mechanisms	safe installation → installation in disturbed state → installation in hazardous condition → dangerous disturbance to installation → release → ignition → fire/explosion → harm → emergency operation
	initiating events/upsets	equipment malfunction, human error, containment failure, structural damage
	external events	traffic problems, bad weather conditions
	event sequences (intermediate events)	equipment malfunction, containment failure, human error, external event, leakage etc. causing release, ignition, fire, explosion, spill
	escalation - domino effects	escalation possible to other parts of the system or to neighbours
	duration of event sequences	can be very short - less than 10 minutes/even momentary - from the initiating event until the substances are released and ignited
	systems response to events/upsets	safety system response: relief valves, disconnection to other parts of the system mitigation system response: vents, flares, sprinklers contingency system response: detection, alarms, procedures
	operator response to events/upsets	planned/ad hoc operations, personnel safety equipment, evacuation
	substances formed during the incident	few
EMERGENCY SUPPORT	basic ways of controlling/fighting the UFOE(s)	evacuate, stop traffic to area, stop flow in pipelines, cover leak, fire fighting
	emergency organisations	planned/dedicated
	special equipment	emergency treatment of people with burns, equipment to reduce/limit the release,
	mitigation systems	collection of oil spills in marine environments
	escape routes	normally described in the internal emergency plans
	alarms	internal warning systems at the installation and along the transfer system (message to supervisors) external warning systems (neighbours, authorities)
	inventories	number of people employed, head on duty, amount of materials present, layout of the installation and the transfer system
	communication lines	contacts to the leader of the emergency operation, contact to head on duty, contact to hospitals, contact between police and fire brigade, contact to authorities
	lines of command	-
	requirements to personnel qualification	knowledge about handling and transfer of chemicals, especially oil and gas

CONTEXT (III)		ENERGY DISTRIBUTION pipelines, storages, reservoirs
	contacts to experts	special emergency operations in case of larger leaks (e.g. blowouts) and fires
	possibilities for an efficient emergency control	primary victims can be difficult to rescue, the emergency forces have to be on-site very fast in order to avoid accident escalation and to reduce accident consequences

TRAINING (I)		ENERGY DISTRIBUTION pipelines, storages, reservoirs
TRAINING OBJECTIVES	time aspects for on-site operations	a fast operation is normally needed to avoid domino effects, the on-site emergency organisation must be at the incident location less than ½ hour after the incident has occurred, fast evacuation is needed
	priority of decisions and actions	evacuate, reduce source, stop release, fire fighting, first aid
	critical conditions	amount of substances released, source strength, ignition source
	constraints on access to incident location	installations: emergency situations are normally taken into account in the layout transfer system: the accident can occur at locations where a fast emergency operation can be difficult/impossible
	early warning of people	internal emergency organisation, police
	evacuation (transport of injured persons)	the accident may develop fast and it is important the personnel/people staying close to the accident location can reach a safety location very fast evacuation of people in high risk zones, transportation of injuries to hospital
	measures for environmental protection	knowledge about substances and materials especially oil and gas, knowledge about dispersion routes in maritime environments
	operations by internal emergency organisation	early detection of an accident, fast call for an emergency, first aid, evacuation, mitigation measures, close down/disconnect other parts of the installation/transfer system
	operations by external emergency organisations	communication, mitigation measures, protective measures, evacuation, first aid
	fields of responsibilities	primary emergency operations by the internal emergency organisation, transferring the responsibility from the internal to the external emergency forces, subsequent emergency operations by the external emergency forces normally the head of the fire brigade is head of the emergency operation
	communication with the public	information about injuries, environmental impact and accident causes information to relatives, neighbours, authorities
	co-operation between organisations	between internal and external emergency organisations, between external emergency organisations (fire brigade, police, hospitals, ambulance service, oil pollution brigade

TRAINING (II)		ENERGY DISTRIBUTION pipelines, storages, reservoirs
PARTICIPANTS	trainees	safety officer, managers/engineers, heads of emergency organisations, key decision makers
	supervisors	external or internal experts
	evaluators	representatives from the company, the authorities, the emergency organisations, decision makers
DATA ACQUISITION	logging	computer logs, video/audio tape recordings
	observations	working climate, stress factors

STATUS (I)		ENERGY DISTRIBUTION - OFFSHORE Explosion on the North Sea oil rig "Piper Alpha" East of Aberdeen, Scotland, 6 July 1988
TERRITORY CHARACTERISTICS	area (e.g. urban, industrial, rural)	Oil rig in the North Sea approx. 280 km north-east of Aberdeen, Scotland.
	population density	226 men on the platform, 38 were Occidental staff and 188 were contractors.
	dispersion routes	Air, sea water.
	meteorological and topographical factors	Wind direction 160-170 degrees; wind speed 10-15 knots; sea conditions: significant wave 0,5-1,5 m, maximum wave 2,0-3,0 m; visibility 25 + km.
RESOURCES	personnel directly involved in the activity	Persons on duty: 62, persons off duty: 164.
	technical configuration	The jacket was a steel structure standing in a water depth of 145 m. Production deck (26 m level): A module, the wellhead module. B module, the production module. Contained two main production separators. C module, the gas compression module. D module, the power generation module. Also contains the emergency generators, the fire pumps and the control room. Firewalls between A, B, C, and D modules. Piper was connected to other platforms and to shore by 4 pipelines, 1 oil and 3 gas. There were two flare booms to allow the flare used to be altered to suit the wind direction. A heat shield was fitted to deflect radiant heat coming from the flare. There were 4 accommodation modules at various levels. The reception area in the main quarters module was designated as an emergency command centre. Helideck on top of the main quarters module and on the Living Quarters West.
	amount and number of chemical substances	Oil export: 119 000 barrels per day. Condensate export: 7 500 barrels per day. Export flow of Tartan gas across Piper: 0,9 millions of standard m^3 per day. Lift gas circulation on Piper: 1,4 millions of standard m^3 per day.
	construction materials	Steel.
	electrical supply system	Main electrical supply: 2 dual firing generators each rated at 24 000 kW. Emergency generator: one turbine-driven diesel-fired generator rated at 800 kW. Drilling generator: one diesel-driven generator with separate emergency backup. Uninterrupted power supplies: 3 battery power supplies. Emergency supply to critical systems and services such as heating, ventilation and air conditioning; instrument air; strategic valves; emergency lightning; general alarm and personal address system.

STATUS (II)		**ENERGY DISTRIBUTION - OFFSHORE** Explosion on the North Sea oil rig "Piper Alpha" East of Aberdeen, Scotland, 6 July 1988
RESOURCES (continued)	communication system	Internal: Personal address system, tannoy on all parts of the platform also in every bedroom. General alarm system, klaxon on all parts of the platform also in every bedroom. 2 systems of telephones for internal communication. 14 UHF radios. External: Tropospheric scatter system. Direct line of sight microwave radio system. These two systems carried telephone, telex, telemetry and computer traffic. INMARSAT system as backup. 36 VHF radios. Piper served as communication link for Claymore and Tartan to shore. Alternative link was the MCP-01 platform.
	transport system	Ship, helicopter, oil and gas pipelines.
PROCESS CONDITION	energy potential	Amount of fuel in initial explosion about 30-80 kg ⇒ maximum peak over-pressure about 0,2 - 0,4 bar.
	temperature, high/low	Gas 10 °C. Oil 67 °C.
	pressure, high/low	Pressure in import and export gas pipelines up to 120 bar. Pressure in export oil line up to 62 bar.
SYSTEMS CONTROL	automation	High.
	instrumentation	High.
	on-line control	Yes.
	process control	Yes.
	operator supervision	Yes in control room.
	safety systems, confinements	Control system, supervision. alarms, process equipment.
ORGANISATION	work organisation	Strategic level: Offshore Installation Manager (OIM) and on-shore headquarters Tactical level: Supervisors and Superintendents of the units Operation level: operators, technicians, riggers, scaffolders, divers
	safety organisation	Safety Supervisor (1), Lead Safety Officer (vacant), Platform Medic (1), Safety Operators (1), Contractor Safety Officers (2).
SOURCES OF INFORMATION	system documentation	Occidental General Safety Procedures Manual, Permit To Work System,
	literature	-
	accident descriptions	-
	information from organisations/consultants	-
	information from authorities	Offshore Emergency Handbook, Merchant Ship Search and Rescue Manual
	validation of information and sources	-
ANALYSIS METHODS	structural aspects	Pump trips: high pressure, overload, lube oil system, pump vibration.
	operational aspects	Failure of supervisors to check work sites before suspending permits to work.
	managerial aspects	Permit to work system, transmission of information at shift handover.

CONTEXT (I)		ENERGY DISTRIBUTION - OFFSHORE Explosion on the North Sea oil rig "Piper Alpha" East of Aberdeen, Scotland, 6 July 1988
INCIDENT	hazard source	Gas, oil, and condensate leaks, blow out.
	loss of confinement	Gas leak, rupture of pipelines, rupture of risers, rupture of equipment.
	uncontrolled flow of energy	Pressurised gas and liquid, chemical energy.
	potential exposure	Explosion, fire, shock wave, heat radiation.
VULNERABLE OBJECTS	people threatened in high risk zones	All 226 persons staying on the platform - out of these 165 persons died.
	people that might be affected	-
	environmental impacts (recipients)	Oil spill to sea.
	impact on property	Oil rig damaged. Loss of oil and gas.
	areas affected by the incident (source distance)	-
SCENARIO	incident mechanisms	Condensate leak from a not leak-tight blind flange assembly at the site of a pressure relief valve on condensate injection pump A, mod.C.
	initiating events/upsets	-
	external events	-
	event sequences (intermediate events)	Trip of condensate injection pump B ⇒ failure to restart pump B ⇒ attempt to start condensate injection pump A ⇒ condensate leak in module C ⇒ gas alarm and explosion ⇒ pipe rupture (crude oil) in module B ⇒ fire.
	escalation - domino effects	-
	duration of event sequences	*21.45 - 21.50:* Trip of B pump. *22.00:* Initial explosion. *22.04 - 22.08*: 3 maydays were sent from the Radio Room. *22.20:* Major explosion (Tartan gas riser). *22.30 - 00.45:* Collapse of the centre of the platform. *22.45:* Fire fighting from the "Tharos". *22.50:* Further explosion (MCP-01 gas riser). *23.27:* Arrival of rescue helicopters. *23.30:* Rupture of Claymore gas riser. *08.15:* The survivors had all reached the shore.
	systems response to events/upsets	Emergency shutdown systems for all pipelines, fire fighting systems.
	operator response to events/upsets	Shutdown procedures, information to crew.
	substances formed during the incident	Combustion products.
EMERGENCY SUPPORT	basic ways of controlling/fighting the UFOE(s)	Evacuate, cover leak, fire fighting.
	emergency organisations	Fire fighting rests with the internal emergency organisation. Maritime search and rescue rests with HM Coastguard. Co-ordination of search and rescue operations by maritime rescue co-ordination centres (MRCCs) and on-scene commander (OSC). OIM is OSC unless the seriousness of the emergency or loss of communication demands otherwise. Helicopters provided by Ministry of Defence at rescue co-ordination centres (RCCs).

CONTEXT (II)		ENERGY DISTRIBUTION - OFFSHORE Explosion on the North Sea oil rig "Piper Alpha" East of Aberdeen, Scotland, 6 July 1988
EMERGENCY SUPPORT (continued)	special equipment	Six totally enclosed lifeboats equipped with a water drench system to cool it in case it had to travel through a burning oil spill. Other life saving appliances. Breathing apparatus. Survival suits. Silver Pit: standby vessel 400 m from Piper equipped with a fast rescue craft. Tharos: support vessel for major emergencies 550 m from Piper equipped with fire-fighting equipment and well killing, a hospital, a fast rescue craft, and a helicopter. Several other ships and fast rescue crafts in the area to pick up survivors.
	mitigation systems	Fire-water deluge system and foam deluge protection. Automatically activated in the area where fire had been detected. Fire pumps (4 pumps. 2 of the pumps had standby diesel drive and were in a fireproof enclosure, these 2 pumps could be put on manual start). Foam injection by an electrical pump backed up by a diesel-driven pump. Emergency shutdown system. Automatic or manually activated. Two automatic systems, a pneumatic and an electrical. The system only closed the oil pipeline not the gas pipelines.
	escape routes	Escape routes were painted with arrows to mark the routes. Signs showing a general layout. Next to the each life raft was situated a single knotted rope to allow escape to sea.
	alarms	Gas detection system: gas detectors in zones and on certain individual items of equipment. Fire detection system: UV flame detectors and heat detectors. Automatically activation of the fire deluge system. Possibility for disabling the automatic action.
	inventories	If a general alarm occurred personnel were instructed to go to their lifeboats. Personnel who could not reach their lifeboats would receive instructions from the emergency command post.
	communication lines	OIM/OSC→ Occidental Emergency Control Centre and MRCC, standby vessel, support vessel, other installations, ships.
	lines of command	-
	requirements to personnel qualification	Knowledge about the installation design and layout.
	contacts to experts	On site.
	possibilities for an efficient emergency control	Piper's fire fighting system failed to operate (pumps set to manual operation because divers were operating near the suction end). No communication between the emergency response teams and the OIM ⇒ individual emergency response.

TRAINING		ENERGY DISTRIBUTION - OFFSHORE Explosion on the North Sea oil rig "Piper Alpha" East of Aberdeen, Scotland, 6 July 1988
TRAINING OBJECTIVES	time aspects for on-site operations	Fast emergency response is crucial (< few minutes).
	priority of decisions and actions	Evacuate, first aid, reduce source.
	critical conditions	-
	constraints on access to incident location	Smoke, flames and heat made the emergency response difficult/impossible.
	early warning of people	-
	evacuation (transport of injured persons)	No alarms or announcements were made. Evacuation via lifeboats and helicopters not possible due to smoke and heat. Evacuees waited for the support vessel to come and pick them up. They were not told that this was not possible. The standby vessel was inadequately equipped.
	measures for environmental protection	Control of oil leaks, collecting oil spill.
	operations by internal emergency organisation	Updated emergency procedures. Emergency exercises. Use lessons learnt from previous incidents for improvements. General safety awareness.
	operations by external emergency organisations	Communication standards. Emergency exercises involving helicopter and vessel services and hospitals.
	fields of responsibilities	OSC, MRCC, Company Emergency Control Centre. The master on Tharos acted as OSC. After about an hour co-ordination with MRCC was established
	communication with the public	Press releases from the Company Emergency Control Centre or the MRCC
	co-operation between organisations	Due to limited communication facilities the MRCC was unable to communicate with the OSC for the first hour of the incident ⇒ inadequate information to RCC.
PARTICIPANTS	trainees	-
	supervisors	-
	evaluators	-
DATA ACQUISITION	logging	-
	observations	-

Reference "Explosion on the North Sea oil rig Piper Alpha, East of Aberdeen, Scotland, 6 July 1988":

The Hon Lord Cullen, *The Public Inquiry into the Piper Alpha Disaster*, Department of Energy, London, 1990

STATUS		ENERGY DISTRIBUTION - PIPELINES Propane explosion Gothenburg, Sweden, 8 May 1981
TERRITORY CHARACTERISTICS	area (e.g. urban, industrial, rural)	industrial
	population density	low
	dispersion routes	air, rain water drainage system
	meteorological and topographical factors	light north-easterly wind, terrain mainly flat with only minor level differences
RESOURCES	personnel directly involved in the activity	operators in control building, engineer in charge
	technical configuration	7 pipelines parallel with one road and crossing another road on a pipe bridge
	amount and number of chemical substances	crude oil from the oil harbour propane, butane, kerosene, petrol, diesel, fuel oil to the centre of Gothenburg the propane pipeline contained 95 $m^3 \cong 50$ tonnes
	construction materials	steel
	electrical supply system	-
	communication system	radio, telephone
	transport system	-
PROCESS CONDITION	energy potential	high
	temperature, high/low	low
	pressure, high/low	low
SYSTEMS CONTROL	automation	-
	instrumentation	-
	on-line control	-
	process control	the pipeline was not transporting any gas at the time of the accident
	operator supervision	yes
	safety systems, confinements	pipeline, control system
ORGANISATION	work organisation	operators, engineer in charge
	safety organisation	-
SOURCES OF INFORMATION	system documentation	-
	literature	-
	accident descriptions	-
	information from organisations/consultants	-
	information from authorities	-
	validation of information and sources	-
ANALYSIS METHODS	structural aspects	shut-off valves on both ends of the pipeline
	operational aspects	fast response (inspection of pipelines) on explosion/gas release alert
	managerial aspects	public accessibility to the pipelines

CONTEXT (I)		**ENERGY DISTRIBUTION - PIPELINES** Propane explosion Gothenburg, Sweden, 8 May 1981
INCIDENT	hazard source	flammable substances (crude oil, propane, butane, kerosene, petrol, diesel)
	loss of confinement	gas leak, pipeline rupture
	uncontrolled flow of energy	pressurised liquid, chemical energy, mechanical energy
	potential exposure	explosion and subsequent fire, heat radiation, shock wave
VULNERABLE OBJECTS	people threatened in high risk zones	firemen in the two trucks, severe burns on two firemen, one killed
	people that might be affected	on-scene emergency personnel, people in a neighbouring residential house
	environmental impacts (recipients)	-
	impact on property	damage to pipeline, damage to rain water drainage system, damage to neighbouring office building, damage to a residential house, damage to parked cars
	areas affected by the incident (source distance)	explosion/fire: 250 m downwind, 100 m upwind, 150 m breadth; shock wave: 120 m; burning vapour cloud covered an area of approx. 40.000 m^2
SCENARIO	incident mechanisms	sabotage by means of explosives
	initiating events/upsets	-
	external events	-
	event sequences (intermediate events)	initial explosion (sabotage) → gas leak → gas cloud → ignition → explosion and fire
	escalation - domino effects	the heat from the fire threatened the integrity of the pipe bridge and the other pipelines, explosion in the rain water drainage system, fire at neighbouring office building, shock wave caused severe damage to a residential house, damage to parked cars
	duration of event sequences	*01.31.50* police notified about an explosion. Personnel at the control-building heard the explosion. Engineer in charge investigated alongside the pipeline; *01.35* police notifies Fire Brigade Alarm Centre; *01.55* fire engineer on duty arrives; *02.00* road blocks established by police and Fire Brigade; *02.20* private car drives through the "fog". Height of "fog": 1,5 m; *02.25* two Fire Brigade trucks drives into the "fog" and the gas cloud explodes followed by a fire at the rupture for about 30 hours
	systems response to events/upsets	automatic shut down of equipment, relief valves
	operator response to events/upsets	awareness about the threat to other equipment
	substances formed during the incident	combustion products
EMERGENCY SUPPORT	basic ways of controlling/fighting the UFOE(s)	evacuate, stop traffic to area, first aid, stop flow in pipeline
	emergency organisations	Fire Brigade Alarm Centre co-ordinating 4 fire brigades and ambulance services, Police

CONTEXT (II)		ENERGY DISTRIBUTION - PIPELINES Propane explosion Gothenburg, Sweden, 8 May 1981
EMERGENCY SUPPORT (continued)	special equipment	-
	mitigation systems	-
	escape routes	-
	alarms	-
	inventories	-
	communication lines	-
	lines of command	-
	requirements to personnel qualification	-
	contacts to experts	-
	possibilities for an efficient emergency control	all propane between the shut-off valves will be released from the pipe

TRAINING		ENERGY DISTRIBUTION - PIPELINES Propane explosion Gothenburg, Sweden, 8 May 1981
TRAINING OBJECTIVES	time aspects for on-site operations	fast response necessary to prevent people from approaching the gas cloud
	priority of decisions and actions	-
	critical conditions	-
	constraints on access to incident location	from the wind direction i.e. north-east
	early warning of people	police
	evacuation (transport of injured persons)	ambulance
	measures for environmental protection	-
	operations by internal emergency organisation	detection of leakage, isolating and shutting down the pipeline, securing other pipelines, co-ordinating emergency operation with the external emergency organisation
	operations by external emergency organisations	warning neighbouring facilities and residents, preventing people from entering the zone of the gas cloud, co-ordinating the emergency operation with the internal emergency organisation
	fields of responsibilities	fire engineer
	communication with the public	information to neighbours
	co-operation between organisations	Fire Brigade Alarm Centre
PARTICIPANTS	trainees	-
	supervisors	-
	evaluators	-
DATA ACQUISITION	logging	-
	observations	-

Reference "Propane explosion, Gothenburg, Sweden, 8 May 1981":

Nilsson, E. (1981), *The propane explosion in Gothenburg 8th May 1981*, Symposium Series, 80, Institution of Chemical Engineers

STATUS (I)		ENERGY DISTRIBUTION - PIPELINES Gas pipeline rupture and explosion Bashkir Autonomous Soviet Rep., 3 June 1989
TERRITORY CHARACTERISTICS	area (e.g. urban, industrial, rural)	rural
	population density	low
	dispersion routes	air
	meteorological and topographical factors	railway tracks runs next to the pipeline, deep hollow between two hills ($\Delta h \cong 35$ m), forest in a valley, wind speed $\cong$ 1 m/s, temperature $\cong$ 18 °C
RESOURCES	personnel directly involved in the activity	pipeline operators in control room
	technical configuration	pipeline length: 1853 km, pipeline diameter: 700 mm pipeline thickness: 9 mm, design pressure: 100 atm, operating pressure: 25-28 atm
	amount and number of chemical substances	10.000 tonnes pr. day (120 kg per sec.) of a mixture of liquefied propane, butane and other light hydrocarbons
	construction materials	metal
	electrical supply system	-
	communication system	-
	transport system	4 pumps (design requires 8 pumps) $\Rightarrow$ decreased operating pressure
PROCESS CONDITION	energy potential	high
	temperature, high/low	low
	pressure, high/low	medium
SYSTEMS CONTROL	automation	low
	instrumentation	pressure measurement. The monitoring system was recognised as being unreliable and inefficient
	on-line control	yes
	process control	recording of pressure
	operator supervision	in control room
	safety systems, confinements	pipeline, control system
ORGANISATION	work organisation	-
	safety organisation	-
SOURCES OF INFORMATION	system documentation	-
	literature	-
	accident descriptions	a similar accident had occurred four months before. No measures taken
	information from organisations/consultants	-
	information from authorities	-
	validation of information and sources	-
ANALYSIS METHODS	structural aspects	railway tracks situated below pipeline level, no telemechanics facilities to allow local or remote control of shutters (valves), pipeline tested periodically by means of hydraulic tests and measurements of the tube thickness

STATUS (II)		ENERGY DISTRIBUTION - PIPELINES Gas pipeline rupture and explosion Bashkir Autonomous Soviet Rep., 3 June 1989
ANALYSIS METHODS	operational aspects	recognising the link between leakage and decrease in pressure
	managerial aspects	inspection of construction work of the pipeline, follow up on previous accidents criteria for construction of pipelines

CONTEXT (I)		ENERGY DISTRIBUTION - PIPELINES Gas pipeline rupture and explosion Bashkir Autonomous Soviet Rep., 3 June 1989
INCIDENT	hazard source	pressurised liquefied propane, butane, other light hydrocarbons (flammable and explosive)
	loss of confinement	gas leak, pipeline rupture
	uncontrolled flow of energy	pressurised liquid, chemical energy, mechanical energy
	potential exposure	explosion (equal to 2000-3000 tonnes TNT) and fire, heat radiation, shock wave
VULNERABLE OBJECTS	people threatened in high risk zones	1244 tickets sold for both trains, several children under 5 years of age (no ticket required) and train staff, trains on fire ⇒ 575 killed and 623 injured
	people that might be affected	the above mentioned
	environmental impacts (recipients)	limited/none
	impact on property	train and pipeline damaged
	areas affected by the incident (source distance)	windows blown out 15 km away
SCENARIO	incident mechanisms	mark left by excavator during construction → mark covered by soil → not discovered by inspection → crack and gas leak
	initiating events/upsets	-
	external events	-
	event sequences (intermediate events)	gas leak (not detected) → ignition caused by two passing trains → explosion and firestorm
	escalation - domino effects	shock wave destroyed 1800 meters of contact wire and railway tracks, forest fire
	duration of event sequences	*20.00* drop in pipeline pressure. Additional pumps turned on to increase pressure; *21.00* local citizens smells gas 4-7 km from the pipeline; *22.50* cargo train passes, driver notices strong smell of gas; *23.10* driver of one of the passenger trains reports strong smell of gas and a belt of fog 30-40 m wide and reaching the contact wires; *23.14* two passenger trains passes in the valley. Explosion and firestorm.
	systems response to events/upsets	warning operators about pressure decrease, automatic shut down of pipeline
	operator response to events/upsets	recognising the link between pressure decrease and gas leak, initiate search for leak, early warning about the possibility of leaking gas
	substances formed during the incident	combustion products (fossil fuel)

CONTEXT (II)		ENERGY DISTRIBUTION - PIPELINES Gas pipeline rupture and explosion Bashkir Autonomous Soviet Rep., 3 June 1989
EMERGENCY SUPPORT	basic ways of controlling/fighting the UFOE(s)	evacuate, stop traffic to area, rescue passengers, first aid, stop flow in pipeline
	emergency organisations	-
	special equipment	-
	mitigation systems	-
	escape routes	-
	alarms	-
	inventories	-
	communication lines	-
	lines of command	-
	requirements to personnel qualification	-
	contacts to experts	-
	possibilities for an efficient emergency control	-

TRAINING		ENERGY DISTRIBUTION - PIPELINES Gas pipeline rupture and explosion Bashkir Autonomous Soviet Rep., 3 June 1989
TRAINING OBJECTIVES	time aspects for on-site operations	very short
	priority of decisions and actions	stop release, first aid, fire fighting
	critical conditions	-
	constraints on access to incident location	-
	early warning of people	radio, TV
	evacuation (transport of injured persons)	-
	measures for environmental protection	-
	operations by internal emergency organisation	early detection of gas leak, shutting down the pipeline, warning/stopping trains
	operations by external emergency organisations	first aid of injuries, transportation of injuries to hospital, fire fighting
	fields of responsibilities	-
	communication with the public	-
	co-operation between organisations	-
PARTICIPANTS	trainees	-
	supervisors	-
	evaluators	-
DATA ACQUISITION	logging	-
	observations	-

Reference "Gas pipeline rupture and explosion, Bashkir Autonomous Soviet Rep., 3 June 1989":

Tsyganov, S.A., *Information on gas pipeline accident in Bashkir Autonomous Soviet Republic (near the city of Ufa)*, Semenov Institute of Chemical Physics, Academy of Sciences of the USSR

APPENDIX E

Marine transport - goods

Accidents

Prince William Sound - oil release (1989, Alaska, USA)
Grays Harbour - oil release (1988, Washington State, USA)

STATUS		MARINE TRANSPORT - GOODS
TERRITORY CHARACTERISTICS	area (e.g. urban, industrial, rural)	harbour, restricted waters, coastal waters, open sea
	population density	low
	dispersion routes	drifting on sea, drifting to coasts, entering sediments
	meteorological and topographical factors	wind direction, force of the wind, currents
RESOURCES	personnel directly involved in the activity	crew, pilot, onshore navigation centres
	technical configuration	single hull vessel, double hull vessel
	amount and number of chemical substances	type and amount of cargo
	construction materials	steel
	electrical supply system	-
	communication system	radio, telephone
	transport system	-
PROCESS CONDITION	energy potential	-
	temperature, high/low	-
	pressure, high/low	-
SYSTEMS CONTROL	automation	automatic pilot on the ship
	instrumentation	-
	on-line control	radar systems, navigation charts
	process control	-
	operator supervision	bridge crew, onshore navigation centres
	safety systems, confinements	tanker hull
ORGANISATION	work organisation	captain, mates, helmsmen
	safety organisation	captain responsible for safety
SOURCES OF INFORMATION	system documentation	technical configuration of the ship, procedures, instructions, safety systems, emergency plans
	literature	information about: dispersions of chemicals and oil at sea; wind and currents; vulnerable environments
	accident descriptions	oil spill incidents, grounding incidents, collision incidents, structural damage incidents, fire/explosion incidents
	information from organisations/consultants	specific analyses on marine transport of dangerous goods
	information from authorities	emergency plans, legislative requirements, approvals, restricted routes
	validation of information and sources	information up to date, information available
ANALYSIS METHODS	structural aspects	reliability of communication systems; structural reliability of tanker hull; release protection (single/double hull tankers); stability; age of vessel
	operational aspects	human reliability assessment of procedural tasks, qualification of personnel, human behaviour in the control of danger
	managerial aspects	manning levels, job overload, planning for oil-spill clean-up, knowledge about currents and wind conditions, safety culture, working discipline, information channels

CONTEXT		MARINE TRANSPORT - GOODS
INCIDENT	hazard source	large amount of chemicals/oil
	loss of confinement	damage to tanker hull, structural damage (e.g. capsizing)
	uncontrolled flow of energy (UFOE)	release of chemicals/oil, fire, explosion
	potential exposure	pollution of marine environment, health hazards
VULNERABLE OBJECTS	people threatened in high risk zones	crew
	people that might be affected	people living in the area, commercial fishermen, tourism, emergency organisations personnel
	environmental impacts (recipients)	damage to ecologically-sensitive areas dead birds, fishes, mammals etc. pollution of coast lines
	impact on property	damage to ship(s), loose of cargo(s)
	areas affected by the incident (source distance)	the source distance can be very long, e.g. 800-1000 km; large areas and coastal lines may be polluted
SCENARIO	incident mechanisms	collision and damage to tanker hull
	initiating events/upsets	human error, structural damage
	external events	-
	event sequences (intermediate events)	navigation/operation $\rightarrow$ collision/damage $\rightarrow$ release of cargo $\rightarrow$ collect released oil/chemicals $\rightarrow$ pump oil/chemicals from damaged ship $\rightarrow$ clean-up activities
	escalation - domino effects	bad weather conditions, currents
	duration of event sequences	oil slicks can be drifting for months
	systems response to events/upsets	collect/skim released oil/chemicals, pump oil/chemicals from damaged ship, emergency call
	operator response to events/upsets	-
	substances formed during the incident	-
EMERGENCY SUPPORT	basic ways of controlling/fighting the UFOE(s)	pump out the cargo from the vessel, skim leaked chemicals/oil, enclose leaked chemicals/oil
	emergency organisations	coast guard; environmental protection authorities; regional response teams
	special equipment	booms, skimmers, dispersants, burning
	mitigation systems	-
	escape routes	-
	alarms	-
	inventories	-
	communication lines	-
	lines of command	-
	requirements to personnel qualification	knowledge about marine environment knowledge about dispersion of oil in marine environment knowledge about currents and meteorological conditions
	contacts to experts	-
	possibilities for an efficient emergency control	medium - depends on the currents and wind conditions the initial efforts and decisions are essential in order to reduce the accident consequences

TRAINING		MARINE TRANSPORT - GOODS
TRAINING OBJECTIVES	time aspects for on-site operations	good possibilities for supervising the release and preparing emergency actions
	priority of decisions and actions	pump out the oil from the ship; skim leaked oil, examination of currents and weather conditions, ship traffic control clean up: removal of oil from beaches, protection of birds and mammals, acceleration of natural recovery; minimisation of economic loss, avoidance of human health-risks
	critical conditions	currents and wind directions
	constraints on access to incident location	the oil spread to a large area
	early warning of people	-
	evacuation (transport of injured persons)	-
	measures for environmental protection	skimmers, dispersants, booms
	operations by internal emergency organisation	stabilise/stop release, call for emergency
	operations by external emergency organisations	clean-up: beaches, animals, inland waterways, open sea
	fields of responsibilities	captain responsible for safety on board the ship, the spiller has primary responsibility for clean-up
	communication with the public	-
	co-operation between organisations	the clean-up activities may involve thousands of people from different organisations which requires a strong co-ordination
PARTICIPANTS	trainees	captains, mates, heads of emergency organisations, heads of environmental protection authorities, heads of coast guards, key decision makers
	supervisors	internal and external experts
	evaluators	representatives from the operators, the authorities, the emergency organisations, training experts
DATA ACQUISITION	logging	computer logs, video/audio tape recordings
	observations	working climate, stress factors

STATUS (I)		MARINE TRANSPORT - GOODS The grounding of Exxon Valdez Prince William Sound Alaska, 24 March 1989
TERRITORY CHARACTERISTICS	area (e.g. urban, industrial, rural)	inland waterways
	population density	very low
	dispersion routes	oil slick drifting on sea and to coast
	meteorological and topographical factors	-
RESOURCES	personnel directly involved in the activity	Exxon Valdez's crew; Vessel Traffic System's (VTS) crew
	technical configuration	300-metres-long supertanker
	amount and number of chemical substances	crude oil containing 0,82% sulphur and 9,2% aromatics the ship was carrying 200.000 ton
	construction materials	steel ?
	electrical supply system	-
	communication system	radio, telephone
	transport system	-
PROCESS CONDITION	energy potential	-
	temperature, high/low	-
	pressure, high/low	-
SYSTEMS CONTROL	automation	automatic pilot on the ship
	instrumentation	-
	on-line control	radar system, navigation charts
	process control	-
	operator supervision	bridge crew Vessel Traffic Centre
	safety systems, confinements	tanker hull (single ?)
ORGANISATION	work organisation	captain, helmsmen, mates
	safety organisation	captain responsible for safety
SOURCES OF INFORMATION	system documentation	-
	literature	-
	accident descriptions	oil spill incidents, grounding incidents, collision incidents
	information from organisations/consultants	-
	information from authorities	-
	validation of information and sources	-
ANALYSIS METHODS	structural aspects	the VTS communication system failed to meet the Coast Guard's requirement of 99,9% operational status; during the evening of March 23rd the Naked Island and Cape Hinchinbrook remote communication sites were inoperable the contractor of the radar system didn't keep the system well maintained and as a result it was inoperable up to 28% of the time Oil Pollution Act of 1990 requiring a gradual introduction of double-hull tankers

STATUS (II)		MARINE TRANSPORT - GOODS The grounding of Exxon Valdez Prince William Sound Alaska, 24 March 1989
ANALYSIS METHODS (continued)	operational aspects	the VTS watchstander thought the radar wasn't working well; the captain had confirmed that he was drinking that day
	managerial aspects	Exxon Shipping Company - reduced manning levels led to fatigue and job overload - there was no established polices regarding procedures to reduce the risks of operating with smaller crews - lack of compliance with Federal statutes regarding work schedules for deck officers - tanker crews had not complied with written company policies regarding drug and alcohol internal policing to ensure compliance U.S. Coast Guard - supporting the reduction of crew sizes leading to fatigue and job overload - deterioration and downgrading of the VTS in Valdez over the years - reorganisation, loss of billets, and use of inexperienced personnel for VTS duties in Valdez Oil Pollution Act of 1990 requiring more rigorous planning for oil-spill clean-up

CONTEXT (I)		MARINE TRANSPORT - GOODS The grounding of Exxon Valdez Prince William Sound Alaska, 24 March 1989
INCIDENT	hazard source	large amount of crude oil
	loss of confinement	damage to tanker hull
	uncontrolled flow of energy (UFOE)	release of crude oil
	potential exposure	oil pollution of marine environment
VULNERABLE OBJECTS	people threatened in high risk zones	-
	people that might be affected	- 16.000 Native Americans the social and cultural impact was severe (fishing, hunting, etc.) - commercial fishing and tourism were in 1989 virtually eliminated by the oil-spill
	environmental impacts (recipients)	40.000 ton were spilled into Prince William Sound; 100.000-300.000 dead birds; dead sea otters; only little amount of oil entered subtidal sediments; fears of long-term damage were lessened by the all-time return of pink salmon to Prince William Sound in 1990
	impact on property	damage to ship; loose of oil the clean-up activities cost more than US $ 2.000.000.000

CONTEXT (II)		MARINE TRANSPORT - GOODS The grounding of Exxon Valdez Prince William Sound Alaska, 24 March 1989
VULNERABLE OBJECTS (continued)	areas affected by the incident (source distance)	the spilled oil was tracked for two months, by which time some had reach a distance of 750 km from the grounding site; the amount of beach affected is estimated to be about 1.500 km; much of the coastline consists of gravel beaches into which the oil penetrated to depths as great as 1 m
SCENARIO	incident mechanisms	the tanker had left the designated shipping lane in order to avoid ice from a nearby glacier, but failed to change course in time to avoid a charted reef
	initiating events/upsets	human oversight and error
	external events	-
	event sequences (intermediate events)	-
	escalation - domino effects	in three days of calm and sunny weather following the grounding, no effective oil containment or clean-up was accomplished; the strong north-easterly winds developed and spread the released oil into the Gulf of Alaska
	duration of event sequences	late on March 23 the helmsman responded to an order from the master to sail the ship 180 deg and put the ship on automatic pilot; 23.47: the ship left the Traffic Separation Scheme going into the inbound lane to avoid ice; 23.55 the third mate ordered a right 10 deg rudder but the vessel did not move to this position, there is a six-minute delay before the third mate and the helmsman respond to the fact that the ship did not begin to turn; 00.02: the light from Bligh Reef was on the wrong side of the ship and the third mate orders a right 20 deg rudder; 00.04: the ship skidded into Bligh Reef; 00.20: the chief engineer stopped the engine; 00.27: VTS was informed about the grounding; 00.30: Port of Valdez was closed for traffic and a tug was send to the grounded tankship; 03.35: representatives from the Marine Safety Office boarded the ship;
	systems response to events/upsets	initial efforts by Exxon Corporation and Aleyska Pipeline Service Company were unsuccessful; the efforts suffered from lack of adequate organisation and equipment
	operator response to events/upsets	-
	substances formed during the incident	-
EMERGENCY SUPPORT	basic ways of controlling/fighting the UFOE(s)	pump out the oil from the tanker, skim leaked oil
	emergency organisations	11.000-12.000 people participated in the emergency and cleaning operations - of these 3.000 offshore (1.000 vessels) Unite States Coast Guard; Alaska Department of Environmental Conservation; regional Response Team
	special equipment	booms, skimmers, dispersants, burning

CONTEXT (III)		**MARINE TRANSPORT - GOODS** The grounding of Exxon Valdez Prince William Sound Alaska, 24 March 1989
EMERGENCY SUPPORT (continued)	mitigation systems	-
	escape routes	-
	alarms	-
	inventories	-
	communication lines	-
	lines of command	-
	requirements to personnel qualification	-
	contacts to experts	-
	possibilities for an efficient emergency control	medium, but due to insufficient actions during the first days after the grounding the accident consequences escalated

TRAINING		**MARINE TRANSPORT - GOODS** The grounding of Exxon Valdez Prince William Sound Alaska, 24 March 1989
TRAINING OBJECTIVES	time aspects for on-site operations	good possibilities for supervising the oil slick and preparing emergency actions
	priority of decisions and actions	pump out the oil from the ship; skim leaked oil, examination of currents and weather conditions, ship traffic control clean up: removal of oil from beaches, protection of birds and mammals, acceleration of natural recovery; minimisation of economic loss, avoidance of human health-risks
	critical conditions	currents and wind directions
	constraints on access to incident location	the oil spread to a large area
	early warning of people	-
	evacuation (transport of injured persons)	-
	measures for environmental protection	-
	operations by internal emergency organisation	-
	operations by external emergency organisations	clean-up: beaches, animals, inland waterways, open sea
	fields of responsibilities	the spiller has primary responsibility for clean-up under the supervision of the US Coast Guard
	communication with the public	-
	co-operation between organisations	-
PARTICIPANTS	trainees	-
	supervisors	-
	evaluators	-
DATA ACQUISITION	logging	-
	observations	-

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STATUS		MARINE TRANSPORT - GOODS Oil spill from the barge "Nestucca" Grays Harb., Wash. State, 22 December 1988
TERRITORY CHARACTERISTICS	area (e.g. urban, industrial, rural)	harbour sea
	population density	low
	dispersion routes	oil slick drifting on sea
	meteorological and topographical factors	seasonal nearshore winter current flowing from south to north onshore winds tidal currents
RESOURCES	personnel directly involved in the activity	crew
	technical configuration	-
	amount and number of chemical substances	Bunker-C oil
	construction materials	-
	electrical supply system	-
	communication system	-
	transport system	-
PROCESS CONDITION	energy potential	-
	temperature, high/low	-
	pressure, high/low	-
SYSTEMS CONTROL	automation	-
	instrumentation	-
	on-line control	-
	process control	-
	operator supervision	-
	safety systems, confinements	tanker hull
ORGANISATION	work organisation	-
	safety organisation	-
SOURCES OF INFORMATION	system documentation	-
	literature	-
	accident descriptions	oil spill incidents
	information from organisations/consultants	-
	information from authorities	-
	validation of information and sources	-
ANALYSIS METHODS	structural aspects	-
	operational aspects	-
	managerial aspects	the Washington State Department of Ecology recommended to tow the barge about 50 km out to the sea (the hope was the oil would drift out the sea and disperse); but a close examination of the prevailing currents and winds at that time of year should have led to a conclusion of a possible drift of the oil northward and onshore.

CONTEXT (I)		MARINE TRANSPORT - GOODS Oil spill from the barge "Nestucca" Grays Harb., Wash. State, 22 December 1988
INCIDENT	hazard source	large amount of Bunker-C oil
	loss of confinement	damage to tanker hull
	uncontrolled flow of energy (UFOE)	release of oil
	potential exposure	oil pollution of marine environment
VULNERABLE OBJECTS	people threatened in high risk zones	-
	people that might be affected	various social groups were affected by the oil spill: commercial fishermen, the local residents, the native Indians, the resort owners, the staff of the national parks and the tourists
	environmental impacts (recipients)	875.000 l fuel oil leaked into the sea the oil hit highly ecologically-sensitive areas more than 7000 dead sea birds
	impact on property	damage to barge and tug
	areas affected by the incident (source distance)	the oil slick drifted from Grays Harbour to Queen Charlotte Islands, about 800 km
SCENARIO	incident mechanisms	collision - damage to tanker hull
	initiating events/upsets	collision - the barge was punctured by a tug towing it during an attempt to retrieve a tow line in rough seas
	external events	-
	event sequences (intermediate events)	to avoid pollution of oyster beds and bird sanctuary the barge was towed about 50 km out to sea in a southwest direction; nearshore current combined with onshore winds and tidal currents moved the oil slick northward
	escalation - domino effects	-
	duration of event sequences	22 December release of oil; 24 December 7000 dead and dying birds began washing up on the Washington coast; 29 December a small slick was tracked but a larger slick headed for Vancouver Island; 1 January the oil was spotted on the southwest coast of Vancouver Island; 3 January heavy black oil was observed at 8 km of beaches at Pacific Rim National Park on the Vancouver Island; 9 January oil was found at the beaches of Bajo Point; 18 January aircraft tracked the movement of an oil slick threatening the Queen Charlotte Islands; 20 January the Scott Islands were hit by the oil; 7 February small oil blobs washed up on Long Beach
	systems response to events/upsets	the Washington State Department of Ecology recommended to tow the barge about 50 km out to the sea (the hope was the oil would drift out the sea and disperse); no Canadian clean-up plan was developed because it was felt that the oil slick would drift out to sea
	operator response to events/upsets	-
	substances formed during the incident	-

CONTEXT (II)		MARINE TRANSPORT - GOODS Oil spill from the barge "Nestucca" Grays Harb., Wash. State, 22 December 1988
EMERGENCY SUPPORT	basic ways of controlling/fighting the UFOE(s)	enclose the barge in an oil boom and pump out the oil skim leaked oil
	emergency organisations	The Canadian Coast Guard; Environment Canada; The Department of Fisheries and Oceans; The British Columbia Ministry of Environment; The Washington State Department of Ecology numerous volunteers (more than 100) were actively involved in the clean-up
	special equipment	oil skimmer
	mitigation systems	-
	escape routes	-
	alarms	-
	inventories	-
	communication lines	-
	lines of command	-
	requirements to personnel qualification	-
	contacts to experts	knowledge about marine environment knowledge about dispersion of oil in marine environment knowledge about currents and meteorological conditions
	possibilities for an efficient emergency control	yes, but a wrong decision was taken concerning towing the oil slick out to sea the oil slick caused damage greatly out of proportion to its size

TRAINING (I)		MARINE TRANSPORT - GOODS Oil spill from the barge "Nestucca" Grays Harb., Wash. State, 22 December 1988
TRAINING OBJECTIVES	time aspects for on-site operations	good possibilities for supervising the oil slick and preparing emergency actions
	priority of decisions and actions	examinations of currents and wind directions, pump oil, skimm oil, clean-up
	critical conditions	currents and wind directions
	constraints on access to incident location	the oil spread to a large area
	early warning of people	-
	evacuation (transport of injured persons)	-
	measures for environmental protection	oil skimmer
	operations by internal emergency organisation	-
	operations by external emergency organisations	-
	fields of responsibilities	-
	communication with the public	-
	co-operation between organisations	-

TRAINING (II)		MARINE TRANSPORT - GOODS Oil spill from the barge "Nestucca" Grays Harb., Wash. State, 22 December 1988
PARTICIPANTS	trainees	-
	supervisors	-
	evaluators	-
DATA ACQUISITION	logging	-
	observations	-

Reference "Oil spill from the barge "Nestucca", Grays Harb., Wash. State, 22 December 1988":

Waldichuk, M. (1989). *The Nestucca Oil Spill,* Marine Pollution Bulletin, **20**, no. 9, pp 419-420.

APPENDIX F

Marine transport - people

Accidents

Zeebrugge - capsize (1987, Belgium)
Skagerrak - fire on ferry (1990, Denmark)

STATUS (I)		MARINE TRANSPORT - PEOPLE
TERRITORY CHARACTERISTICS	area (e.g. urban, industrial, rural)	harbour, sea, inland waterways
	population density	passengers (ca 1000) and crew members (ca 100)
	dispersion routes	-
	meteorological and topographical factors	tide water, wind speed, temperature (air & water) harbour, sea, inland waterways
RESOURCES	personnel directly involved in the activity	crew members
	technical configuration	car deck, accommodation decks, lounges (bars, restaurants etc.), bridge deck, engine room, fuel storage tanks, utility systems
	amount and number of chemical substances	-
	construction materials	steel, plastics, fabrics, wood
	electrical supply system	separate supply system emergency power system (diesel)
	communication system	phone, UHF/VHF radio, telegraph
	transport system	-
PROCESS CONDITION	energy potential	-
	temperature, high/low	water temperature can be low
	pressure, high/low	-
SYSTEMS CONTROL	automation	low
	instrumentation	fire/smoke alarms may be installed, control system
	on-line control	-
	process control	-
	operator supervision	inspection of specific operations, e.g. closing of bow doors registration of the traffic inspection rounds (fire, entering of water)
	safety systems, confinements	marine equipment, hull of ship, smoke alarms and fire fighting system, control systems, bow doors, lifeboats
ORGANISATION	work organisation	deck officers, engine officers, catering officers crew members referring to the officers
	safety organisation	the captain is responsible for the safety of passengers, crew and property one of the officers is also safety officer safety groups ?
SOURCES OF INFORMATION	system documentation	technical configuration of the ship, structural construction, procedures, instructions, safety systems, internal emergency plans, shipping routes
	literature	-
	accident descriptions	accidents/incidents/near misses occurred with passenger ships databases concerning transportation at sea
	information from organisations/consultants	rescue systems (alarms, lifeboats, escape routes etc.)
	information from authorities	legislative requirements and approvals external emergency organisations and operations
	validation of information and sources	information up to date, information available

STATUS (II)		MARINE TRANSPORT - PEOPLE
ANALYSIS METHODS	structural aspects	design and stability, structural reliability, manoeuvre vulnerability, fire detection and fire fighting
	operational aspects	human reliability, assessment of procedural tasks, qualification of personnel, human behaviour in the control of danger
	managerial aspects	fields of responsibility, information channels, safety culture, working discipline, language/communication problems, decision-making hierarchy, interaction with other socio-technical systems (e.g. authorities, emergency organisations), public relations

CONTEXT (I)		MARINE TRANSPORT - PEOPLE
INCIDENT	hazard source	fire and smoke, entering water
	loss of confinement	leak in hull/bow doors ignition source, fire
	uncontrolled flow of energy (UFOE)	entering water release of smoke and toxic gases
	potential exposure	fire, smoke, release of toxic materials capsize, sinking, shipwreck
VULNERABLE OBJECTS	people threatened in high risk zones	passengers and crew members
	people that might be affected	-
	environmental impacts (recipients)	-
	impact on property	damage to ferry
	areas affected by the incident (source distance)	-
SCENARIO	incident mechanisms	human error, management error, ignition source human error, management error, collision, grounding, structural damage
	initiating events/upsets	equipment malfunction, human error, collision, structural damage, ignition (fire raiser)
	external events	bad weather and traffic conditions
	event sequences (intermediate events)	safe transport → transport in disturbed stage (ignition/leakage) → transport in hazardous conditions (flames/entering of water) → dangerous disturbances to transport (escalation of fire and release of smoke containing toxic substances/capsize) → harm to humans → emergency operation
	escalation - domino effects	solely the passengers, crew members and the property can be affected
	duration of event sequences	½ to 1 hour - can be shorter
	systems response to events/upsets	fire and smoke detectors, fire fighting securing of watertight doors and watertightness in bulkheads
	operator response to events/upsets	report upsets and make corrective actions, warning of passengers and crew members
	substances formed during the incident	many different chemicals can be formed during a fire, combustion of construction and covering materials (CO_2, CO, NO_x, HCN etc.)

CONTEXT (II)		MARINE TRANSPORT - PEOPLE
EMERGENCY SUPPORT	basic ways of controlling/fighting the UFOE(s)	rescue passengers and crew from ship fire fighting
	emergency organisations	internal emergency organisation on board air forces (helicopters), navies, naval personnel, divers, fire men police, ambulances, hospitals
	special equipment	diving gear, lights, ropes, ladders
	mitigation systems	-
	escape routes	normally described in the emergency plan, but can be difficult to use in an emergency situation due to smoke/fire/capsize
	alarms	fire and smoke detectors fire alarms, warning of passengers and crew members alarms for entering of water (e.g. on the car deck)
	inventories	number of people on board, ship layout
	communication lines	contacts to the leader of the emergency operation, contact to the captain
	lines of command	the captain is the responsible leader on board
	requirements to personnel qualification	-
	contacts to experts	salvage operation experts
	possibilities for an efficient emergency control	low, the accident location can be in the open sea and bad weather condition can make it difficult to carry out the emergency operations

TRAINING (I)		MARINE TRANSPORT - PEOPLE
TRAINING OBJECTIVES	time aspects for on-site operations	fast activation of the emergency organisation on board, fast establishment of an external emergency organisation a fast emergency operation is normally needed, cold water or fire make fast rescue critical
	priority of decisions and actions	rescue passengers and crew first aid control fire or entering of water
	critical conditions	fire escalation, ignition of materials in cabins and lounges critical amount of water on car deck, stability of the ship
	constraints on access to incident location	non predictable
	early warning of people	internal emergency organisation on board
	evacuation (transport of injured persons)	a fast evacuation may be needed, it may be necessary to evacuate a large amount of people crowd movement, getting people from the cabins/lounges to the deck, use of lifeboats and life jackets
	measures for environmental protection	-
	operations by internal emergency organisation	early detection of a hazardous situation, fast call for an emergency, early warning of passengers and crew members, evacuation

TRAINING (II)		MARINE TRANSPORT - PEOPLE
TRAINING OBJECTIVES (continued)	operations by external emergency organisations	controlling priorities of the emergency tasks, it may be difficult to reach the accident location
	fields of responsibilities	the captain is responsible for the emergency operations on board ad hoc what concerns the external emergency operations, a control centre will normally be established what concerns the external emergency operations
	communication with the public	information about injuries information to the relatives, authorities
	co-operation between organisations	between on-board and external emergency organisations national and international air forces and navies, authorities, hospitals, ships close to the accident location
PARTICIPANTS	trainees	the captain, the safety officer, officers from the air forces and the navies, heads of authorities, other key decision makers
	supervisors	national and international experts
	evaluators	representatives from the authorities, the air forces, the navies training experts
DATA ACQUISITION	logging	computer logs, video/audio tape recordings
	observations	working climate, stress factors

STATUS (I)		MARINE TRANSPORT - PEOPLE Capsize "Herald of Free Enterprise" Zeebrugge (Belgium), 6 March 1987
TERRITORY CHARACTERISTICS	area (e.g. urban, industrial, rural)	Harbour and sea
	population density	459 passengers; 80 crew members
	dispersion routes	-
	meteorological and topographical factors	Tide water high/low, current
RESOURCES	personnel directly involved in the activity	Master (captain), Chief Officer, Second Officer, bosun, assistant bosun
	technical configuration	The outer bow doors were hydraulically operated and swung horizontally about vertical axes, on radius arms. They met at the centre line so that one door stowed to port and the other to starboard. The inner bow doors were lock gate type. They opened in a forward direction. Watertightness was maintained by hydraulically compressing tubular neoprene seals around the outer periphery of the doors. The berth at Zeebrugge was a single level berth designed for loading on to the bulkhead deck of single deck ferries. The ship berthed bows to the berth and it was necessary to trim the ship by the head to allow the ramp to reach the upper car deck. Two ballast tanks were filled with up to 310 m^3 water. The ballast tanks were not connected to high capacity pumps for filling and emptying.
	amount and number of chemical substances	-
	construction materials	-
	electrical supply system	Three internal combustion driven alternators. Emergency power: one diesel driven alternator.
	communication system	Tannoy address system (for summoning crew members) + VHF radio
	transport system	-
PROCESS CONDITION	energy potential	-
	temperature, high/low	Water temperature: low.
	pressure, high/low	-
SYSTEMS CONTROL	automation	An operator, assistant bosun, operates the bow doors manually at the car deck.
	instrumentation	Control box for operating the bow doors.
	on-line control	None
	process control	None
	operator supervision	It was the duty of the officer loading the main car deck to ensure that the bow doors were secure when leaving the port.
	safety systems, confinements	Marine equipment, hull of ship, control systems, bow doors.

STATUS (II)		MARINE TRANSPORT - PEOPLE Capsize "Herald of Free Enterprise" Zeebrugge (Belgium), 6 March 1987
ORGANISATION	work organisation	Standing orders stated that Heads of Departments had to report to the Master immediately if any deficiency were observed which caused their departments to be unready for sea in any respect at the due sailing time. In the absence of any such report the Master should assume, that the vessel was ready for sea in all respects.
	safety organisation	The Master of the ship was responsible for the safety of his ship and every person on board.
SOURCES OF INFORMATION	system documentation	Ship's Standing Orders. Some instructions were not clearly worded and not enforced.
	literature	-
	accident descriptions	5 similar near misses had not resulted in any change of procedures or installation of control systems.
	information from organisations/consultants	-
	information from authorities	Legal requirements for Passenger Ship Construction.
	validation of information and sources	Annual refits of Certificates
ANALYSIS METHODS	structural aspects	The ship was often overloaded because a reliable procedure for measuring the weight of vehicles was not in place. Draught gauges to indicate that the ship was overloaded were not installed.
	operational aspects	-
	managerial aspects	The Chief Officer (loading officer) felt under pressure to leave the berth immediately after the completion of loading. The practice was for the officer on the car deck to call the bridge and tell the quartermaster to give the order "harbour stations". Frequently the order "harbour stations" was given before loading was complete. The order was given as soon as the Chief Officer decided that by the time the crew arrived at their stations everything would be ready for the ship to proceed to sea. At "harbour stations" the Chief Officer has to be on the Bridge. If the Chief Officer was required to remain on the car deck until the bow doors had been closed the order "harbour stations" should have been delayed. According to "Bridge and Navigational Procedures" the Chief Officer should be on the Bridge approximately 15 minutes before the ship's sailing time.

CONTEXT (I)		MARINE TRANSPORT - PEOPLE Capsize "Herald of Free Enterprise" Zeebrugge (Belgium), 6 March 1987
INCIDENT	hazard source	Large amounts of water in the hull threatens the ship's stability.
	loss of confinement	Leak in hull/bow doors.

CONTEXT (II)		MARINE TRANSPORT - PEOPLE Capsize "Herald of Free Enterprise" Zeebrugge (Belgium), 6 March 1987
INCIDENT (continued)	uncontrolled flow of energy	Entering water.
	potential exposure	Capsize and sinking.
VULNERABLE OBJECTS	people threatened in high risk zones	Passengers and crew members onboard the ship. 150 passengers and 38 crew members died.
	people that might be affected	-
	environmental impacts (recipients)	-
	impact on property	Damage to ferry.
	areas affected by the incident (source distance)	-
SCENARIO	incident mechanisms	Human error: Failure of the bosun to close the bow doors. Failure of the loading officer (Chief Officer) to ensure that the bow doors were secure before leaving the port. Failure of the bosun to inform that no one was operating the bow doors. Failure of the Master to ensure that the ship was ready for departure. Socio-technical error: Pressure to leave the harbour early. Failure of the company to provide clear instructions and to enforce the instructions. Failure of the company to learn lessons from previous similar incidents.
	initiating events/upsets	Failure to close bow doors or secure that bow doors are watertight. Collision and damage to hull at car deck level or lover.
	external events	-
	event sequences (intermediate events)	Loading of vehicles on the car deck completed and the crew called to "harbour stations". Assistant bosun asleep ⇒ he did not show up on the car deck to close the bow doors. The loading officer, Chief Officer, left the car deck without having assured himself that the bow doors were secured. ⇒ The Chief Officer entered the Bridge and the Master assumed that the ship is ready for departure. ⇒ The ship departed and proceeded to sea. ⇒ Large quantities of water flooded the car deck and caused the capsize. ⇒ The "Sanderus" informed Port Control Zeebrugge that the ship had capsized.
	escalation - domino effects	-
	duration of event sequences	18.05: Departure from the berth. 18.24: Leaving harbour, passing the outer mole. 18.28: Capsize, Port Control Zeebrugge informed. 18.28: Ships begin searching for survivors at the wreck and down tide. 18.55: Mayday relay transmitted by Ostende Radio. 19.00: The first two divers supplied. 19.10: The first rescue helicopter over the wreck. 19.25: The first Belgian diving team aboard the wreck. 03.25: All rescue teams left the wreck until daylight.
	systems response to events/upsets	Securing of watertight doors and watertightness in bulkheads.

CONTEXT (III)		MARINE TRANSPORT - PEOPLE Capsize "Herald of Free Enterprise" Zeebrugge (Belgium), 6 March 1987
SCENARIO (continued)	operator response to events/upsets	Report upsets and make corrective actions immediately.
	substances formed during the incident	-
EMERGENCY SUPPORT	basic ways of controlling/fighting the UFOE(s)	Rescue passengers and crew from ship.
	emergency organisations	Belgian Air Force (helicopters), Belgian Navy (divers). Royal Naval personnel. Dutch Naval personnel. German Naval personnel. 20 UK divers. Police. Firemen. Port Emergency Services. Ambulances. 6 Hospitals. Red Cross volunteers.
	special equipment	Diving gear, lights, ropes, ladders.
	mitigation systems	-
	escape routes	The ship was arranged on a semi open plan layout with no side exit at all for a considerable length fore and aft. Consequently a large number of people had to be saved through starboard side windows which had been broken by rescuers. Because the ship was on her beam ends it was difficult to move around inside the ship because transverse alleyways became deep vertical shafts. The emergency lightning was not functioning because parts were immersed when the ship was on her beam ends. Furthermore the emergency generator was incapable of operating at large angles of heel.
	alarms	No draught gauges to indicate that the ship was overloaded. No indicator of the position of the bow doors/alarm for open bow doors. No alarm for water on the car deck.
	inventories	-
	communication lines	-
	lines of command	-
	requirements to personnel qualification	-
	contacts to experts	Knowledge about the ship's layout was provided by crew members from the ship and from crew members from other Townsend-Thorsen ferries.
	possibilities for an efficient emergency control	Good since the accident was reported immediately and the ship did not sink. A total of 32 ships, several helicopters, and more than 20 divers participated in the rescue operation.

TRAINING (I)		MARINE TRANSPORT - PEOPLE Capsize "Herald of Free Enterprise" Zeebrugge (Belgium), 6 March 1987
TRAINING OBJECTIVES	time aspects for on-site operations	The cold water made fast rescue critical. Very little time for corrective actions and subsequently for initiating an internal rescue operation.
	priority of decisions and actions	Rescue passengers and crew, first aid.
	critical conditions	Critical amount of water, the ship's stability.

TRAINING (II)		MARINE TRANSPORT - PEOPLE Capsize "Herald of Free Enterprise" Zeebrugge (Belgium), 6 March 1987
TRAINING OBJECTIVES (continued)	constraints on access to incident location	Windows with toughened glass were broken and people could escape through the hole. Windows with fire resistant laminated glass do not provide means of escape. Divers were needed to access the submerged parts of the ship.
	early warning of people	-
	evacuation (transport of injured persons)	People above the surface inside the ship were evacuated though the broken windows. Helicopter noise made voice communication almost impossible and the listening for hammering from survivors trapped inside the ship below the surface was also impossible. The helicopters lights blinded the rescuers and rescues. The down-draught made it difficult to stand on the side of the ship. Reporters jumped aboard rescue vessels when these left the harbour and then on to the "Herald of Free Enterprise" and were a hindrance to the rescue operation
	measures for environmental protection	-
	operations by internal emergency organisation	Emergency procedures. General safety awareness. Encourage corrective actions. Encourage the information of superiors in case of faults, defects, and deficiencies. Use lessons learnt from previous incidents to improve procedures and equipment.
	operations by external emergency organisations	Communication standards. Emergency operations involving rescue services and hospitals.
	fields of responsibilities	A control centre was set up at the Pilot Station at Zeebrugge. The "Cowdenburg" was On Scene Commander until 22.50 when the "Duke of Anglia" took over. The Chief Officer (OSC) was on board the "Herald of Free Enterprise" and was in VHF communication with his own ship. For some time he was unaware of the existence of any shore centre.
	communication with the public	Reporters on the scene.
	co-operation between organisations	Not possible to communicate directly with the helicopters.
PARTICIPANTS	trainees	-
	supervisors	-
	evaluators	-
DATA ACQUISITION	logging	-
	observations	-

Reference "Capsize Herald of Free Enterprise, Zeebrugge (Belgium), 6 March 1987":

Department of Transport, *The Merchant Shipping Act 1894, mv Herald of Free Enterprise*, Report of Court No. 8074, Formal Investigation, 1987 (75 pages).

STATUS (I)		MARINE TRANSPORT - PEOPLE Fire at passenger ferry "Scandinavian Star" 7th April 1990, Skagerrak (Norway, Denmark)
TERRITORY CHARACTERISTICS	area (e.g. urban, industrial, rural)	Sea, Skagerrak
	population density	383 passengers 99 crew members
	dispersion routes	air, sea
	meteorological and topographical factors	-
RESOURCES	personnel directly involved in the activity	-
	technical configuration	141.8 m long, 22.7 m wide ferry, built 1971 , totally 9 decks. Capacity 857 sleeping passengers, 280 cars. For short travels, the capacity was totally 1408 passengers. the ship was divided in three fire zones vertically
	amount and number of chemical substances	CO_2, CO and HCN developed by fire. Deficit in O_2
	construction materials	nitriles and isocyanates in wall materials at corridors and cabins
	electrical supply system	-
	communication system	-
	transport system	-
PROCESS CONDITION	energy potential	-
	temperature, high/low	-
	pressure, high/low	-
SYSTEMS CONTROL	automation	-
	instrumentation	smoke detectors, not in passenger areas. stands for manually activating fire alarms, fire alarm horns (siren) serviced from the bridge, public address system (not fire resistant)
	on-line control	-
	process control	ventilation controlled from bridge
	operator supervision	fire inspection rounds taking 45 min., any passenger or crew member could trigger the fire alarm
	safety systems, confinements	fire doors could be operated locally and from the bridge fire registers to block ventilation were manually controlled fire hydrants and fire hose smoke diving equipment for 7 persons sprinklers on car deck
ORGANISATION	work organisation	-
	safety organisation	as Master of the ship, the captain was also responsible for safety. The Chief Officer was responsible for the everyday safety work

STATUS (II)		MARINE TRANSPORT - PEOPLE Fire at passenger ferry "Scandinavian Star" 7th April 1990, Skagerrak (Norway, Denmark)
SOURCES OF INFORMATION	system documentation	-
	literature	-
	accident descriptions	-
	information from organisa-tions/consultants	certification: Lloyd's Register since 1987
	information from authorities	ship registered in Bahamas IMO guidelines A.647 (about safe operations) SOLAS 1960 with certain extra specifications national rules for ships in Norwegian, Swedish or Danish waters. STWC convention and IMO recommendation A 481 (about crew)
	validation of information and sources	-
ANALYSIS METHODS	structural aspects	-
	operational aspects	-
	managerial aspects	-

CONTEXT (I)		MARINE TRANSPORT - PEOPLE Fire at passenger ferry "Scandinavian Star" 7th April 1990, Skagerrak (Norway, Denmark)
INCIDENT	hazard source	wall materials etc. in corridor
	loss of confinement	fire
	uncontrolled flow of energy (UFOE)	fire and smoke moved from corridor through staircase to other parts of ship
	potential exposure	heat, oxygen deficit, developed gas (CO and HCN) and smoke.
VULNERABLE OBJECTS	people threatened in high risk zones	passengers at sleep in cabins, crew members
	people that might be affected	all persons on board
	environmental impacts (recipients)	-
	impact on property	ship, cars, luggage
	areas affected by the incident (source distance)	-
SCENARIO	incident mechanisms	fire in heap of bedcloths in back end of corridor, deck 3, lower cardeck
	initiating events/upsets	probably arsonry less than half an hour prior to this fire, another fire had started, which was controlled
	external events	

CONTEXT (II)		MARINE TRANSPORT - PEOPLE Fire at passenger ferry "Scandinavian Star" 7th April 1990, Skagerrak (Norway, Denmark)
SCENARIO (continued)	event sequences (intermediate events)	0200 am (appr.) fire start 0215 fire alarm sounded 0224 Mayday call 0225 "Stena Saga" contacted 0225 Mayday signal relayed to Sola (from Tjoeme Radio) 0237-0242 contacts made between Norwegian, Swedish and Danish emergency centres 0247 Stena Saga appointed Co-ordinator Surface Search 0250 Stena Saga at Scandinavian Star 0328 rescue to Stena Saga initiated 0335 first rescue helicopter at Scandinavian Star 0530 first professional smoke diver lands on Scandinavian Star
	escalation - domino effects	fire spread via staircase
	duration of event sequences	-
	systems response to events/upsets	signals from smoke detectors. no signals acquired from fire start area, because there were no persons in that fire zone, accordingly fire doors were not operated from the bridge and fire spread was easy. some fire doors closed only partially
	operator response to events/upsets	fire alarms sounded fire doors closed in pattern corresponding to smoke detection organised fire fighting was not attempted some smoke diving equipment was used there were a few attempts at using fire hoses, but without success
	substances formed during the incident	CO, CO_2, HCN
EMERGENCY SUPPORT	basic ways of controlling/fighting the UFOE(s)	stop moving energy (smoke and gas) control fire (stop oxygen flow) remove vulnerable items (evacuate)
	emergency organisations	preparatory plans included: - emergency plan (overview) - boat and raft launching plan - emergency plan (procedures) - evacuation plan - emr-list indicating the functions of each individual under emergency - crew list emergency plans had been adapted from an earlier version for a crew of 228, the present crew of appr.100 was mostly new, external operations coordinated by Emergency Command Centre Sola in Norway, whereas the passenger ferry "Stena Saga" acted as Co-ordinator Surface Search, air traffic for the emergency was coordinated by On Scene Commander-air

CONTEXT (III)		MARINE TRANSPORT - PEOPLE Fire at passenger ferry "Scandinavian Star" 7th April 1990, Skagerrak (Norway, Denmark)
EMERGENCY SUPPORT (continued)	special equipment	lifeboats used generally, the safety equipment was not properly tested and serviced
	mitigation systems	sprinklers. Many found blocked by rust in later test.
	escape routes	escape routes and muster stations given on Passengers' Boarding Cards, however, these cards not administered on this particular voyage. escape route signs not complete, and somewhere even misleading some problems with language on signs, which not all crew members could read
	alarms	auditive / horns. Sound level found afterwards to be partly below adequate level
	inventories	evacuees were not registered before leaving the ship
	communication lines	co-ordinators Sola and Stena Saga unable to communicate on radiochannel 16 (international emergency channel) also troubles with communications between Stena Saga and the air traffic commander.
	lines of command	a regular emergency organisation was not set in operation during the accident individual crew members did a good job with the evacuation
	requirements to personnel qualification	safety training and certification for smoke diving not updated only an inadequate no. were certified for conducting lifeboat rescue
	contacts to experts	external smoke divers and medical experts joined the rescue operations
	possibilities for an efficient emergency control	reduced sight due to smoke neither fire or evacuation drills had been conducted (as required)

TRAINING		MARINE TRANSPORT - PEOPLE Fire at passenger ferry "Scandinavian Star" 7th April 1990, Skagerrak (Norway, Denmark)
TRAINING OBJECTIVES	time aspects for on-site operations	fire on a ship may develop very fast, and summoning passengers at sleep in cabins is rather time consuming. Checking passenger areas is counterproductive to fire fighting and rescue, in that it occupies evacuation space and implies moving in conflicting directions
	priority of decisions and actions	rescue is easier, if fire becomes limited or even stopped
	critical conditions	suffocation, poisoning, inferior visibility
	constraints on access to incident location	smoke, evacuees, goods
	early warning of people	reaction times /sensors /crew alertness, decisions and actions / passengers awakening
	evacuation (transport of injured persons)	life boat operations checking and accounting, medical support
	measures for environmental protection	-
	operations by internal emergency organisation	the ferry's emergency organisation and practical arrangements mustering stations, individual tasks
	operations by external emergency organisations	higher level organisations, control centres on shore (sea and air)
	fields of responsibilities	emergency command lines and duties
	communication with the public	-
	co-operation between organisations	patterns of responsibilities and collaboration rules for communication
PARTICIPANTS	trainees	-
	supervisors	-
	evaluators	-
DATA ACQUISITION	logging	-
	observations	-

Reference "Fire at passenger ferry "Scandinavian Star" 7th April 1990, Skagerrak (Norway, Denmark)":

Norges Offentlige Utredninger: *"Scandinavian Star"-ulykken, 7.april 1990.* Hovedrapport. NOU 1991:1A. (In Norwegian).

APPENDIX G

Aviation

Accidents

Washington National Airport - collision with bridge (1982, USA)
Leicestershire - air crash on motorway (1989, England)

STATUS		AVIATION
TERRITORY CHARACTERISTICS	area (e.g. urban, industrial, rural)	urban, industrial, rural
	population density	high, medium, low
	dispersion routes	-
	meteorological and topographical factors	visibility, weather conditions, wind speed, temperature, surface conditions soft/hard/plan/rough)
RESOURCES	personnel directly involved in the activity	crew members (cabin crew, flight service crew) airport personnel, tower team
	technical configuration	air craft type and manufacture
	amount and number of chemical substances	jet fuel (5-10 tonnes)
	construction materials	-
	electrical supply system	-
	communication system	radio, telephone
	transport system	-
PROCESS CONDITION	energy potential	high
	temperature, high/low	-
	pressure, high/low	-
SYSTEMS CONTROL	automation	high
	instrumentation	engine instruments display flight instruments display
	on-line control	yes
	process control	flight data recorder, cockpit voice recorder
	operator supervision	cabin crew (captain, officers)
	safety systems, confinements	engine, sustained energy, control systems
ORGANISATION	work organisation	cabin crew (captain, officers), flight service crew
	safety organisation	captain responsible for the aircraft, the tower team responsible for the traffic control
SOURCES OF INFORMATION	system documentation	certified pilots, certified air craft
	literature	manuals, handbooks, procedures
	accident descriptions	air crashes, near misses
	information from organisations/consultants	the flight company, the flight manufacturing company, pilots associations
	information from authorities	accident investigation teams, transport authorities
	validation of information and sources	information up to date, information available
ANALYSIS METHODS	structural aspects	design of the aircraft, safety equipment, seat design, aircraft floor, fire warning equipment
	operational aspects	human error (pilot(s), maintenance engineers, traffic controllers), layout of the instrument panel, training and experience of pilots, qualification and education of crew members, communication between cabin crew and flight service crew, procedure for failure check
	managerial aspects	workloads, maintenance and test programmes, communication via radio transmission, communication between fire brigade and ambulance service, co-operation between the fire and medical services, co-ordination of activities, communication between hospitals, update and amendment of emergency plans, winter operations training, emergency operations in different areas (urban, industrial, rural (e.g. mounts))

CONTEXT		AVIATION
INCIDENT	hazard source	crash, collision, large amount of flammable fuel
	loss of confinement	loss of sustained energy
	uncontrolled flow of energy (UFOE)	gravitation, loss of mechanical energy
	potential exposure	crash
VULNERABLE OBJECTS	people threatened in high risk zones	crew members, passengers, people living/staying in the target area
	people that might be affected	passers-by, people living/staying in the vicinity of the target area, emergency organisations personnel
	environmental impacts (recipients)	-
	impact on property	damage to aircraft, damage to buildings and infra structure
	areas affected by the incident (source distance)	-
SCENARIO	incident mechanisms	human error, engine failure, terrorism
	initiating events/upsets	insufficient inspection, insufficient maintenance, design error, human error
	external events	traffic density, weather conditions
	event sequences (intermediate events)	takeoff from airport → loss of stability/loss of energy → call for an emergency → air crash
	escalation - domino effects	harm to people in the target area, damage to buildings and infra structure in the target area
	duration of event sequences	the accident may develop very fast from the failure is realised until the air crash
	systems response to events/upsets	instruments indicating engine and flight conditions, fire alarms
	operator response to events/upsets	e.g. close down of one of the engines, identification of an area for an emergency landing
	substances formed during the incident	-
EMERGENCY SUPPORT	basic ways of controlling/fighting the UFOE(s)	redirect/change flight course, evacuate target area, fire prevention
	emergency organisations	airport fire department, area communication circuit of the defence civil preparedness agency, fire and police departments, ambulance services, hospitals
	special equipment	helicopters, pumps, fire boats, fire fighting, fire prevention
	mitigation systems	-
	escape routes	-
	alarms	fire alarms, radar monitor control, engine failure alarms
	inventories	-
	communication lines	-
	lines of command	-
	requirements to personnel qualification	knowledge about the injuries and the hospitals abilities and capabilities training for water rescue in winter conditions
	contacts to experts	a flight engineer on board could have contributed to more correct decisions and actions
	possibilities for an efficient emergency control	low, primary victims can be difficult to rescue

TRAINING		AVIATION
TRAINING OBJECTIVES	time aspects for on-site operations	the development of the accident course may be very fast a large number of survivors may need a very fast medical treatment
	priority of decisions and actions	the most badly injured shall be removed first distribution of patients between hospitals fire prevention and protection environment protection acquiring adequate equipment and special forces personnel (divers)
	critical conditions	aircraft crash, iced water avoid ignition of the jet fuel
	constraints on access to incident location	the accident may occur in an impassable area e.g. mountains
	early warning of people	-
	evacuation (transport of injured persons)	adequate equipment for rescue: boats, divers, helicopters transportation of a large number of serious injuries from the accident location to the hospitals
	measures for environmental protection	aircraft fuel might leak from the aircraft
	operations by internal emergency organisation	identify emergency, initial response (usually on the airport area)
	operations by external emergency organisations	emergency response outside the airport transport and medical treatment of injuries fire prevention and protection traffic control
	fields of responsibilities	-
	communication with the public	police, authorities
	co-operation between organisations	ad hoc establishment of emergency organisations which may cause co-operation and communication problems
PARTICIPANTS	trainees	flight captain, tower team leader, heads of emergency organisations, co-ordinators/leaders from the hospitals, key decision makers
	supervisors	experts from the authorities and emergency organisations
	evaluators	training experts, representatives from the accident investigation teams, the line organisations, the authorities, the emergency organisations, the airport tower crew
DATA ACQUISITION	logging	computer logs, video/audio tape recording
	observations	working climate, stress factors (selection of injuries for medical treatment)

STATUS (I)		AVIATION Aircraft collision with 14th Street Bridge Washington National Airport, 13 January 1982
TERRITORY CHARACTERISTICS	area (e.g. urban, industrial, rural)	urban
	population density	5 km south of the general centre of Washington D.C. the areas surrounding the airport are populated. Arlington County, Virginia to the west. City of Alexandria, Virginia to the south. District of Columbia to the north
	dispersion routes	-
	meteorological and topographical factors	ceiling: 60 m; visibility: 800 m; weather: moderate snow; temperature: -4 °C; wind: 6 m/s (010°) the airport is located on the west bank of the Potomac River
RESOURCES	personnel directly involved in the activity	Air Florida Air Florida Wash. maintenance representative; Air Florida station manager; Air Florida assistant station manager; captain (pilot-in-command); first officer; (3 cabin flight attendants) Washington Airport personnel tug operator; ground (local) controller American Airlines 2 Trump Vehicle (de-icing); operators
	technical configuration	Boeing 737-222 maximum authorised takeoff weight: 49,5 tonnes gross takeoff weight: 46,5 tonnes 2 Pratt & Whitney JT8D-9A turbo-fan engines. Takeoff thrust 6,6 tonnes each
	amount and number of chemical substances	11,8 tonnes Jet-A fuel
	construction materials	-
	electrical supply system	-
	communication system	radio, telephone
	transport system	-
PROCESS CONDITION	energy potential	high
	temperature, high/low	low
	pressure, high/low	-
SYSTEMS CONTROL	automation	low
	instrumentation	Engine instruments, especially Engine Pressure Ratio gauges (EPR); Exhaust Gas Temperature; Fuel flow; Engine rotational speed (N_1, N_2) Flight instruments, especially airspeed indicator: stickshaker (device warning of an impending stall)
	on-line control	yes
	process control	Flight Data Recorder; Cockpit Voice Recorder
	operator supervision	captain and first officer
ORGANISATION	safety systems, confinements	engines, sustained energy, control systems
	work organisation	flightcrews routinely reverse duties on alternate legs of flight, but the captain remains pilot-in-command on the aircraft
	safety organisation	tower team supervisor; operations and safety

STATUS (II)		AVIATION Aircraft collision with 14th Street Bridge Washington National Airport, 13 January 1982
SOURCES OF INFORMATION	system documentation	certified pilots in accordance with Federal Aviation Administration (FAA) regulations; certified aircraft in accordance with FAA requirements
	literature	B-737 Flight Manual - Air Florida flightcrew manual; Boeing Operations Bulletins Air Traffic Control Handbook; FAA Bulletins; Air Florida Maintenance Manual: American Airlines Maintenance Manual
	accident descriptions	after the accident several examples of similar occurrences with other aircrafts were identified
	information from organisations/consultants	Boeing Bulletins
	information from authorities	National Transportation Safety Board recommendations; FAA Bulletins
	validation of information and sources	engineering simulator at Boeing Corp.
ANALYSIS METHODS	structural aspects	icing of the compressor inlet pressure probe produces false/low EPR readings; snow or slush adhering to the surface of the aircraft, will degrade the aerodynamic performance
	operational aspects	violating flight manual guidance; responding to alternative engine instrument readings
	managerial aspects	winter operation training ; emphasising winter operation (subfreezing) procedures; evaluation of crew experience in winter operations

CONTEXT (I)		AVIATION Aircraft collision with 14th Street Bridge Washington National Airport, 13 January 1982
INCIDENT	hazard source	contamination of the forward leading edge of the wings additional weight by snow/slush/ice contamination reverse thrust can blow snow toward the front of the aircraft ice blocking of pressure inlet probes when engine anti-ice is not used engine exhaust gasses of preceding aircraft limited ramp space, constrained taxi areas ⇒ perceived as constraint on de-icing possibilities traffic density low visibility runway condition
	loss of confinement	loss of sustained energy
	uncontrolled flow of energy	gravitation, loss of mechanical energy
	potential exposure	crash, collision with bridge and plunge into river
VULNERABLE OBJECTS	people threatened in high risk zones	74 passengers; 5 crew members
	people that might be affected	people in cars on the 14th Street Bridge
	environmental impacts (recipients)	the Potomac River

CONTEXT (II)		AVIATION Aircraft collision with 14th Street Bridge Washington National Airport, 13 January 1982
VULNERABLE OBJECTS (continued)	impact on property	14th Street Bridge damaged, airplane damaged
	areas affected by the incident (source distance)	-
SCENARIO	incident mechanisms	failure to use engine anti-ice during ground operation; take off with snow/slush/ice on the airfoil surfaces (due to prolonged ground delay between de-icing and takeoff clearance); violating flight manual guidance; failure to reject takeoff; limited winter operations experience of the flightcrew
	initiating events/upsets	-
	external events	traffic density, weather conditions
	event sequences (intermediate events)	de-icing completed (different procedures/operators on left and right side) → first tug attempts to push the aircraft back from the gate, but fails → reverse thrust used (30 - 90 sec's.) → aircraft pushed back with tug equipped with chains → taxi and completion of pretakeoff checklist, aircraft crew discussed level of contamination on the aircraft → de-icing attempted by approaching engine exhaust gasses of preceding aircraft → takeoff, the stickshaker sounds → collision with 14th Street Bridge, plunge into the ice-covered Potomac River 1,4 km from the departure end of the runway
	escalation - domino effects	destruction of fuselage and cabin floor → loss of occupant restraint (nonsurvivable) structural damage to the bridge
	duration of event sequences	*15.10*: de-icing completed; *15.15*: aircraft closed up; *15.25*: tug 1; *15.35*: tug 2; *15.38 - 15.59:* taxi and pretakeoff checklist; *15.48*: "de-icing" behind preceding aircraft; *16.00*: takeoff; *16.01*: aircraft collision with bridge, plunging into the Potomac River
	systems response to events/upsets	de-icing requirements, procedures and facilities; equipment for winter rescue operations; collaboration plans for airport emergency response organisation and community emergency response organisations; response plans with assurance that a residual rescue response capability is available at all times
	operator response to events/upsets	flight crew experience and training in winter operations emergency response teams experience and training in winter rescue operations
	substances formed during the incident	-

CONTEXT (III)		AVIATION Aircraft collision with 14th Street Bridge Washington National Airport, 13 January 1982
EMERGENCY SUPPORT	basic ways of controlling/fighting the UFOE(s)	redirect/change flight course, evacuate target area (not relevant, too slow), leave aircraft before eventual fire after crash
	emergency organisations	Washington National Airport fire department; Washington Metropolitan Area Communication Circuit of the Defence Civil Preparedness Agency; Arlington fire and police departments; U.S. Park Police; District of Columbia fire and police departments; Fairfax fire department; Alexandria fire department
	special equipment	Washington National Airport airboat (not tested for performance on ice); District of Columbia fire boat and harbour boat (unable to break ice); U.S. Park Police helicopter; No equipment available for performance on ice
	mitigation systems	-
	escape routes	-
	alarms	local controller follows the aircraft on radar monitor or visually (not possible due to obscured visibility)
	inventories	-
	communication lines	local controller → tower team supervisor → Washington National Airport fire department and external emergency response organisations
	lines of command	-
	requirements to personnel qualification	training for water rescue in winter conditions
	contacts to experts	-
	possibilities for an efficient emergency control	emergency response organisations were not adequately equipped for the emergency

TRAINING (I)		AVIATION Aircraft collision with 14th Street Bridge Washington National Airport, 13 January 1982
TRAINING OBJECTIVES	time aspects for on-site operations	parts of the aircraft submerged in very cold water ⇒ fast rescue necessary. 30 minutes into the emergency, several units were redirected to a train accident at the Smithsonian Metro station
	priority of decisions and actions	rescue/fire/environment protection/acquiring adequate equipment and special forces personnel(divers)
	critical conditions	aircraft crash, iced water
	constraints on access to incident location	river ice covered
	early warning of people	-
	evacuation (transport of injured persons)	adequate equipment for rescue: boats with ice breaking capability, divers, rescue nets for use by helicopters
	measures for environmental protection	aircraft fuel might leak from the aircraft

TRAINING (II)		AVIATION Aircraft collision with 14th Street Bridge Washington National Airport, 13 January 1982
TRAINING OBJECTIVES	operations by internal emergency organisation	identify emergency, initial response (usually on the airport area)
	operations by external emergency organisations	emergency response outside the airport
	fields of responsibilities	internal emergency response team → external emergency response teams
	communication with the public	-
	co-operation between organisations	tower team supervisor, rescue units emergency response plans involving the airport and the surrounding community emergency response organisations
PARTICIPANTS	trainees	-
	supervisors	-
	evaluators	-
DATA ACQUISITION	logging	-
	observations	-

Reference "Aircraft collision with 14th Street Bridge, Washington National Airport, 13 January 1982":

Aircraft Accident Digest 1982 No. 29, *Boeing 737-222, N62AF, collision with 14th Street Bridge, near Washington National Airport*, Washington D.C., United States on 13 January 1982. Report No. NTSB-AAR-82-8 released by the National Transportation Safety Board, United States, International Civil Aviation Organisation

STATUS		AVIATION Air crash on the M1 motorway in Leicestershire Kegworth, United Kingdom, 8 January 1989
TERRITORY CHARACTERISTICS	area (e.g. urban, industrial, rural)	rural, motorway
	population density	low
	dispersion routes	-
	meteorological and topographical factors	the air crash occurred at approximately 20.24 the ground was hard
RESOURCES	personnel directly involved in the activity	eight crew members Heathrow Airport personnel, tower team East Midlands Airport personnel, tower team
	technical configuration	Boeing 737-400
	amount and number of chemical substances	4210 kg fuel
	construction materials	-
	electrical supply system	-
	communication system	radio, telephone
	transport system	-
PROCESS CONDITION	energy potential	high
	temperature, high/low	low
	pressure, high/low	-
SYSTEMS CONTROL	automation	high
	instrumentation	engine instruments display flight instruments display
	on-line control	yes
	process control	flight data recorder, cockpit voice recorder
	operator supervision	captain, first officer, second officer
	safety systems, confinements	engine, sustained energy, control systems
ORGANISATION	work organisation	cabin crew (captain, officers) flight service crew
	safety organisation	captain responsible for the aircraft, the tower team responsible for the traffic control
SOURCES OF INFORMATION	system documentation	certified pilots, certified air craft
	literature	manuals, handbooks, procedures
	accident descriptions	-
	information from organisations/consultants	the Boeing company, British Midland
	information from authorities	Air Accident Investigation Branch (AAIB)
	validation of information and sources	-
ANALYSIS METHODS	structural aspects	design of the aircraft, safety equipment, seat design, fire warning equipment
	operational aspects	human error (pilot(s), maintenance engineers, traffic controllers), layout of the instrument panel, training and experience of pilots, communication between cabin crew and flight service crew, procedure for failure check
	managerial aspects	workloads, maintenance and test programmes, communication via radio transmission, communication between fire brigade and ambulance service, co-operation between the fire and medical services, co-ordination of activities, communication between hospitals, update and amendment of emergency plans

CONTEXT (I)		**AVIATION** Air crash on the M1 motorway in Leicestershire Kegworth, United Kingdom, 8 January 1989
INCIDENT	hazard source	crash, collision, large amount of flammable fuel
	loss of confinement	loss of sustained energy
	uncontrolled flow of energy (UFOE)	gravitation, loss of mechanical energy
	potential exposure	crash
VULNERABLE OBJECTS	people threatened in high risk zones	117 passengers, 8 crew 47 fatalities (passengers only), 74 serious injuries, 5 minor injuries (firemen)
	people that might be affected	passers-by on the motorway
	environmental impacts (recipients)	-
	impact on property	aircraft damaged, damage to infra structure
	areas affected by the incident (source distance)	-
SCENARIO	incident mechanisms	human error, the wrong engine was closed down
	initiating events/upsets	failure of the engine fan blade (resulting from equipment and supplies inadequacies), vibration caused a failure of the fan blade while the aircraft were climbing to between 25.000 and 30.000 feet
	external events	-
	event sequences (intermediate events)	as the aircraft was climbing the crew experienced severe vibration through the controls and a smell of smoke was coming through the air conditioning unit ⇒ passengers saw sparks and flames emerging from the left-hand engine ⇒ the pilots decided to close down the starboard (right-hand) engine ⇒ the flight service crew failed to inform the pilots that they have shut down the wrong engine ⇒ the pilots did not check visually the status of the engine ⇒ problem of competing radio transmission traffic on the wavelength used by the stricken aircraft ⇒ 2-4 miles from the runway the pilot reported a second failure in the left-hand engine ⇒ the aircraft landed on the motorway of some 115 knots, the aircraft broke into three main pieces
	escalation - domino effects	-
	duration of event sequences	*19.52* take of from Heathrow, *20.12* full emergency was declared *20.24* air crash, *20.30* three major hospitals in the area were mobilised, *20.35* foam was applied from the southbound carriageway of the M1, *20.37* the first ambulance reach the scene, *21.09* a senior officer arrived, *22.00* still 45-50 passengers in the aircraft, *02.00* 4 passengers trapped in the aircraft, *04.00* the last passenger was free
	systems response to events/upsets	there was no instrument fire warning on the flight dock panel, no indication of the fire source

CONTEXT (II)		AVIATION Air crash on the M1 motorway in Leicestershire Kegworth, United Kingdom, 8 January 1989
SCENARIO (continued)	operator response to events/upsets	on basis of a "combination of heavy engine vibration, noise, shuddering and an associated smell of fire" the cabin crew made a decision to close down the starboard (right-hand) engine
	substances formed during the incident	-
EMERGENCY SUPPORT	basic ways of controlling/fighting the UFOE(s)	redirect/change flight course, evacuate target area, avoid fire
	emergency organisations	30 ambulances requested to cope with the large number of survivors the police concerned with controlling the traffic three hospitals were mobilised 700 people were on site at various stages during the disaster
	special equipment	15 pumps from the airport fire service, Derbyshire, Nottinghamshire and Leicestershire brigades
	mitigation systems	-
	escape routes	-
	alarms	-
	inventories	-
	communication lines	handhold communications equipment were interfered by electrical equipment and the noise at the site the Leicestershire ambulance service's mobile communication centre was inoperative (90% failures in ground communication)
	lines of command	a senior ambulance officer organised the transportation of injuries
	requirements to personnel qualification	knowledge about the injuries and the hospitals abilities and capabilities
	contacts to experts	a flight engineer on board could have contributed to more correct decisions and actions
	possibilities for an efficient emergency control	primary victims can be difficult to rescue

TRAINING (I)		AVIATION Air crash on the M1 motorway in Leicestershire Kegworth, United Kingdom, 8 January 1989
TRAINING OBJECTIVES	time aspects for on-site operations	a large number of survivors who needed a very fast medical treatment
	priority of decisions and actions	the most badly injured should be removed first but comparing arrival times at the hospitals shows that those survivors who were removed first was not as badly injured as those removed later distribution of patients between hospitals was not adequate, overload at one of the hospitals which received 40 patients over a 1 h 38 min. period
	critical conditions	it was important during the whole disaster period to avoid ignition of the jet fuel

TRAINING (II)		AVIATION Air crash on the M1 motorway in Leicestershire Kegworth, United Kingdom, 8 January 1989
TRAINING OBJECTIVES (continued)	constraints on access to incident location	-
	early warning of people	-
	evacuation (transport of injured persons)	88 injured were transported to the hospitals
	measures for environmental protection	-
	operations by internal emergency organisation	-
	operations by external emergency organisations	transport and medical treatment of injuries fire prevention and protection traffic control
	fields of responsibilities	-
	communication with the public	-
	co-operation between organisations	a tighter relationship between the fire and ambulance service communication and co-ordination of activities between the different organisations affected by the disaster
PARTICIPANTS	trainees	-
	supervisors	-
	evaluators	-
DATA ACQUISITION	logging	-
	observations	-

Reference "Air crash on the M1 motorway in Leicestershire, Kegworth, United Kingdom, 8 January 1989":

D. Smith, (1992). *The Kegworth Air Crash: A Crises in Three Phases ?*, Disaster Management, volume 4 no 2, p. 63-72.

APPENDIX H

Transport by road

Accidents

Möbling - release of phenol (1982, Austria)
Los Alfaques - campsite disaster (1978, Spain)

STATUS (I)		TRANSPORT BY ROAD
TERRITORY CHARACTERISTICS	area (e.g. urban, industrial, rural)	urban, industrial, rural
	population density	high, medium, low
	dispersion routes	puffs and plumes by air (combustion products, gaseous release) heavy gases by air (gaseous release) liquids to soil and subsoil water liquids to marine recipients
	meteorological and topographical factors	wind direction and speed, weather conditions, visibility, darkness, surface roughness, buildings and obstructions
RESOURCES	personnel directly involved in the activity	few, often only the driver
	technical configuration	traction unit, tanker, cargo materials (containers, drums, sacks etc.)
	amount and number of chemical substances	normally only one chemical substance/mixture, 20-40 tonnes more than one chemical substance/mixture can be transported by the same cargo
	construction materials	steel, plastic
	electrical supply system	-
	communication system	mobile telephone
	transport system	-
PROCESS CONDITION	energy potential	high ⇒ medium
	temperature, high/low	medium
	pressure, high/low	high ⇒ medium
SYSTEMS CONTROL	automation	-
	instrumentation	low
	on-line control	-
	process control	-
	operator supervision	the lorry driver
	safety systems, confinements	tanker, packaging materials
ORGANISATION	work organisation	lorry driver, transport organisation
	safety organisation	-
SOURCES OF INFORMATION	system documentation	description of the tanker, lorry, packing materials and their structural stability, instruction to the lorry driver, information on chemical substances and handling of spills, selection of transport routes (restricted routes)
	literature	traffic accident data bases, traffic planning
	accident descriptions	accident/incident/near misses occurred with different types of lorries and goods
	information from organisations/consultants	investigations on traffic accidents
	information from authorities	information about transportation of dangerous goods, national speed limits
	validation of information and sources	information up to date, information available

STATUS (II)		TRANSPORT BY ROAD
ANALYSIS METHODS	structural aspects	loading of tanker, provide appropriate pumps/valves/tanks etc. for reloading of spills, structural stability of the tanker in case of collision, driving properties of the lorry, stability of the lorry in case of swaying
	operational aspects	qualification (education and training) of lorry driver, equipment for personnel protection against chemical exposure, procedures for loading and unloading
	managerial aspects	education and training of the emergency teams, access to information about chemical substances, labelling of dangerous goods, provide cordon around the incident location, clarification of fields of responsibilities, planning of resting time for the emergency personnel, "minimal consequence" (restricted) routes, logistics of getting emergency services to and the large numbers of serious casualties from the disaster location.

CONTEXT (I)		TRANSPORT BY ROAD
INCIDENT	hazard source	flammable/explosive/radioactive/toxic/ecotoxic substances
	loss of confinement	structural damage to tanker/container/drum/sack etc.
	uncontrolled flow of energy (UFOE)	leakage, release
	potential exposure	inhalation, skin contact, fire and heat radiation, explosion and missile, chemical substances to marine recipients
VULNERABLE OBJECTS	people threatened in high risk zones	lorry driver, people from the emergency organisations, people living/staying close to the accident location
	people that might be affected	passers-by, people affected by polluted or contaminated water
	environmental impacts (recipients)	pollution of marine recipients causing damage to flora and fauna, contamination of soil
	impact on property	damage to lorry, buildings, houses, infra structure
	areas affected by the incident (source distance)	in case of fire/explosion about 300-500 m from the accident location pollution of marine recipients may cause long distance effects
SCENARIO	incident mechanisms	solo-accidents, collision, containment failure
	initiating events/upsets	the driver lose control with the lorry (human error), the lorry is involved in a traffic accident, structural damage to tanker/container/drum/sack etc.
	external events	traffic problems, weather conditions, insufficient knowledge about the incident and the chemicals released

CONTEXT (II)		TRANSPORT BY ROAD
SCENARIO (continued)	event sequences (intermediate events)	lorry driver lose control/lorry malfunction ⇒ the lorry sways ⇒ collision with a tree/buildings/other car ⇒ deformation of the tanker ⇒ release ⇒ ignition ⇒ fire/explosion
	escalation - domino effects	harm to people, fire spread, missiles, pollution of vulnerable recipients
	duration of event sequences	can be very short - less than 20 minutes/even momentary - from the initiating event until the substances are released
	systems response to events/upsets	-
	operator response to events/upsets	planned/ad hoc operations personnel safety equipment
	substances formed during the incident	many different chemicals can be formed during a fire (combustion and decomposition products)
EMERGENCY SUPPORT	basic ways of controlling/fighting the UFOE(s)	evacuate, fire fighting, reload chemicals, use absorbing materials, redirect flow away from vulnerable recipients
	emergency organisations	ad hoc, local fire brigade, police, hospitals, ambulance service
	special equipment	emergency treatment of people exposed to toxic substances, equipment for personnel protection, equipment for reloading chemicals
	mitigation systems	e.g. transportable basins for collection of water from fire fighting, collection of chemical/oil spills in marine recipients
	escape routes	-
	alarms	-
	inventories	amount and type of chemicals in the cargo
	communication lines	contacts to leader of the emergency operations, contact to hospitals, contact to the transport company, contact to authorities responsible for environmental protection
	lines of command	-
	requirements to personnel qualification	knowledge about handling and properties of chemical substance
	contacts to experts	specific knowledge about chemicals
	possibilities for an efficient emergency control	primary victims can be difficult to rescue, in case of chemical release to vulnerable recipients severe environmental damage can be difficult to avoid

TRAINING		TRANSPORT BY ROAD
TRAINING OBJECTIVES	time aspects for on-site operations	in case of fire/explosion the accident can escalate within few minutes a fast operation can be needed to limit/avoid release to vulnerable recipients
	priority of decisions and actions	first aid, call for emergency, fire fighting, stop traffic, limit release, redirect flow, warn people, clean up, reload spill
	critical conditions	large amount of flammable/explosive/toxic substances, traffic problems
	constraints on access to incident location	it is not possible on beforehand to predict the incident location
	early warning of people	police
	evacuation (transport of injured persons)	the accident course may develop fast and a fast evacuation is needed logistical problems of getting emergency services to, and the serious casualties from the accident location
	measures for environmental protection	spill combating equipment
	operations by internal emergency organisation	-
	operations by external emergency organisations	reload the released substances, stop traffic, transport of injuries, avoid contamination of soil, marine recipients and the ground water, inform the people living close the incident location
	fields of responsibilities	the local fire brigade officer responsible for the emergency operations
	communication with the public	police, authorities
	co-operation between organisations	ad hoc establishment of emergency organisation which may cause co-operation problems transport accidents will often occur at public areas and it is important to prevent that passers-by are getting access to the accident location
PARTICIPANTS	trainees	safety officers at the transport company, heads of external emergency organisations, key decision makers
	supervisors	experts from authorities and emergency organisations
	evaluators	representatives from the transport company, the line organisations, the authorities, the emergency organisations, training experts
DATA ACQUISITION	logging	computer logs, video/audio tape recording
	observations	working climate, stress factors

STATUS		TRANSPORT BY ROAD Release of phenol Möbling, Kärnten, Austria, 19 July 1982
TERRITORY CHARACTERISTICS	area (e.g. urban, industrial, rural)	urban, main road close to St. Veit an der Glan
	population density	high
	dispersion routes	water, air
	meteorological and topographical factors	the accident occurred short after midnight, dark
RESOURCES	personnel directly involved in the activity	the lorry driver
	technical configuration	traction unit (10 tonnes) with a tanker (13 tonnes)
	amount and number of chemical substances	23 tonnes phenol (60-70°C)
	construction materials	steel ?
	electrical supply system	-
	communication system	-
	transport system	-
PROCESS CONDITION	energy potential	-
	temperature, high/low	medium
	pressure, high/low	-
SYSTEMS CONTROL	automation	-
	instrumentation	-
	on-line control	-
	process control	-
	operator supervision	-
	safety systems, confinements	tanker
ORGANISATION	work organisation	-
	safety organisation	-
SOURCES OF INFORMATION	system documentation	-
	literature	-
	accident descriptions	-
	information from organisations/consultants	-
	information from authorities	-
	validation of information and sources	-
ANALYSIS METHODS	structural aspects	reloading of spill, provide appropriate pumps, tanks, valves etc.
	operational aspects	personnel protection equipment against chemical exposure
	managerial aspects	education and training of the emergency teams, access to information about chemical substances, labelling of dangerous goods, provide cordon around the incident location, clarification of fields of responsibilities, planning of resting time for the emergency personnel

CONTEXT (I)		TRANSPORT BY ROAD Release of phenol Möbling, Kärnten, Austria, 19 July 1982
INCIDENT	hazard source	large amount of a toxic and ecotoxic chemical substance, corrosive by skin contact
	loss of confinement	structural damage to tanker
	uncontrolled flow of energy (UFOE)	leakage, release
	potential exposure	inhalation, skin contact, liquids to the river Gurk and ground water
VULNERABLE OBJECTS	people threatened in high risk zones	people from the fire brigade and the police, the lorry driver, people living in Möbling 7 fire men were highly dangerous exposed (poisoning, skin corrosion)
	people that might be affected	passers-by, people getting/using water from the river or the area
	environmental impacts (recipients)	only minor damage to marine recipients, no impact to ground water 1000 m^3 contaminated soil was removed
	impact on property	damage to lorry, damage to crash fences
	areas affected by the incident (source distance)	8000 litres phenol released but the conditions in the surroundings (air temperature and soil properties) caused the phenol to solidify and only minor amounts of chemicals were released to the river (but phenol can cause severe damage to flora and fauna of marine recipients, e.g. 1 g phenol in 100 l water may cause death to fishes)
SCENARIO	incident mechanisms	release of phenol from the tanker due to structural damage
	initiating events/upsets	the lorry swayed and the tanker broke away from the lorry; the sheets and insulation were damaged; the tanker cracked
	external events	-
	event sequences (intermediate events)	the lorry continued for about 150 m zigzagging; the lorry tanker was deformed but no leakage
	escalation - domino effects	-
	duration of event sequences	00.45: a person living close to the incident location called the police and he started on his own to stop the traffic; 01.00: arrival of local fire brigade, they called for a major emergency and requested for assistance; due to language problems (the lorry driver was Italian), bad labelling and insufficient chemical knowledge the substance was not identified and four fire men were directly exposed to the phenol, the four men were sent to the hospital; 01.30: gas and emergency alarm was initiated by the police; 03.30: the correct papers were found and the substance was identified; 10.30: a tanker for reloading of the phenol was provided; the reloading caused a lot of trouble due to problems with pumps and valves in total the on-site emergency operations lasted about 14 hours
	systems response to events/upsets	-

CONTEXT (II)		TRANSPORT BY ROAD Release of phenol Möbling, Kärnten, Austria, 19 July 1982
SCENARIO (continued)	operator response to events/upsets	-
	substances formed during the incident	phenol
EMERGENCY SUPPORT	basic ways of controlling/fighting the UFOE(s)	reload chemicals, use absorbing materials, redirect flow away from vulnerable recipients
	emergency organisations	fire brigades, police
	special equipment	pumps, valves and tanks which are appropriate for transferring substances which are solids at 25°C, equipment for personnel protection insufficient to protect against phenol exposure
	mitigation systems	-
	escape routes	-
	alarms	-
	inventories	-
	communication lines	-
	lines of command	-
	requirements to personnel qualification	insufficient information and knowledge about chemicals lead to severe exposure to humans
	contacts to experts	contact to a chemists but very late during the incident course
	possibilities for an efficient emergency control	in this case good, but phenol can cause severe environmental damage

TRAINING (I)		TRANSPORT BY ROAD Release of phenol Möbling, Kärnten, Austria, 19 July 1982
TRAINING OBJECTIVES	time aspects for on-site operations	a fast operation can be needed to avoid release to vulnerable marine recipients
	priority of decisions and actions	stop traffic, limit release, redirect flow, warn people, clean up, reload spill
	critical conditions	temperature of phenol, amount of chemicals
	constraints on access to incident location	-
	early warning of people	in the morning the people living close to the incident location were informed by the radio and the fire men walked from house to house and informed people about possible poisoning of the ground water
	evacuation (transport of injured persons)	no evacuation, four people from the fire brigade were hospitalised
	measures for environmental protection	-
	operations by internal emergency organisation	-
	operations by external emergency organisations	reload the released phenol, stop traffic, transport of injuries, avoid contamination of the river and the ground water, inform the people living close the incident location

TRAINING (II)		TRANSPORT BY ROAD Release of phenol Möbling, Kärnten, Austria, 19 July 1982
TRAINING OBJECTIVES (continued)	fields of responsibilities	the local fire brigade officer responsible for the emergency operations
	communication with the public	-
	co-operation between organisations	the co-operation did not work very well a lot of people including bystanders were giving their viewpoints on the situation and what to do the public did get access to the incident location, which caused a lot of confusion
PARTICIPANTS	trainees	-
	supervisors	-
	evaluators	-
DATA ACQUISITION	logging	-
	observations	-

Reference "Release of phenol, Möbling, Kärnten, Austria, 19 July 1982":

Arpe, F.L. (1983). *Fenolulykke i Østrig - en tankevækkende indsats,* Brandværn 7/83, p. 4-8. (In Danish).

STATUS (I)		TRANSPORT BY ROAD Campsite "Los Alfaques"- flash fire and fireball San Carlos de la Rapita; Spain, 11 July 1978
TERRITORY CHARACTERISTICS	area (e.g. urban, industrial, rural)	Recreational area, beach, campsite.
	population density	High, guests at the campsite, people at the beach. When the accident occurred about 500-600 people stayed at the campsite.
	dispersion routes	Air.
	meteorological and topographical factors	Sunshine, temperature above 30°C, a light to moderate breeze from the sea (wind direction west). Campsite between coastal road and beach. Cars, caravans, tents etc. were situated were close to each other. Between the campsite and the road was a brick wall.
RESOURCES	personnel directly involved in the activity	The lorry driver.
	technical configuration	Traction unit with a tanker. No pressure relief on the tanker.
	amount and number of chemical substances	23 tonnes pressurised propylene on this occasion. The maximum load of propylene ought to have been approximately 19 tonnes.
	construction materials	High tensile steel.
	electrical supply system	-
	communication system	-
	transport system	-
PROCESS CONDITION	energy potential	High.
	temperature, high/low	-
	pressure, high/low	High.
SYSTEMS CONTROL	automation	-
	instrumentation	No metering device nor any mechanism to prevent overfilling.
	on-line control	-
	process control	-
	operator supervision	The tanker was loaded in a haphazard way, the only metering device was a weighbridge at the company. If the tanker was overfill the driver could burn off the excess with a device like a flame thrower.
	safety systems, confinements	Tanker.
ORGANISATION	work organisation	-
	safety organisation	-
SOURCES OF INFORMATION	system documentation	-
	literature	-
	accident descriptions	-
	information from organisations/consultants	-
	information from authorities	-
	validation of information and sources	-

STATUS (II)		TRANSPORT BY ROAD Campsite "Los Alfaques"- flash fire and fireball San Carlos de la Rapita; Spain, 11 July 1978
ANALYSIS METHODS	structural aspects	On occasion the returning vehicle had been loaded with anhydrous ammonia, a cargo having a detrimental effect on the integrity of the high tensile steel tank. Sensible filling precautions with accurate metering and check weighing are basic essentials for safety.
	operational aspects	Proper loading/unloading and transport procedures shall be available.
	managerial aspects	"Minimal consequence" routes should be planned by discussions between supplier, transporter, receiver and emergency services. Logistical problems of getting emergency services to, and the large numbers of serious casualties from the disaster location.

CONTEXT (I)		TRANSPORT BY ROAD Campsite "Los Alfaques"- flash fire and fireball San Carlos de la Rapita; Spain, 11 July 1978
INCIDENT	hazard source	Flammable and explosive substances.
	loss of confinement	Structural damage to tanker.
	uncontrolled flow of energy (UFOE)	Chemical energy, flash fire, BLEVE (Boiling Liquid Expanding Vapour Explosion) induced fireball .
	potential exposure	Fire, fireball, heat radiation missile.
VULNERABLE OBJECTS	people threatened in high risk zones	210 fatalities, app. 250 injuries - of these 150 with heavy burns.
	people that might be affected	The people staying at the campsite and the beach, passers-by.
	environmental impacts (recipients)	-
	impact on property	Damage to cars, tents, caravans, campsite etc.
	areas affected by the incident (source distance)	About 10.000 m^2 of the campsite affected by the fire. Missiles (piece of the tanker) found up to 350 m from the lorry.
SCENARIO	incident mechanisms	Release of propylene form the tanker. The structural reliability of the tank was weakened due to overfilling of the tank and previous transport of anhydrous ammonia.
	initiating events/upsets	The lorry crashed into the brick wall (cause unknown) damaging the tanker causing an initial partial loss of propylene into the campsite.
	external events	-

CONTEXT (II)		**TRANSPORT BY ROAD** Campsite "Los Alfaques"- flash fire and fireball San Carlos de la Rapita; Spain, 11 July 1978
SCENARIO (continued)	event sequences (intermediate events)	The initial partial loss of propylene squirted into the campsite. Then there was a small scale deflagration or flash fire which travelled back to the leaking tanker and which burned there for a short time before the weakened vessel BLEVE'd. The vehicle was torn into four main pieces. The rear portion of the tank rocketed to the NW and on chrashing back down, sledged and bumped along until finally lodging in a wall of a restaurant 350 m distant. The mid section was shot sideways into the campsite. The nose cap and endcap were thrown 60 m and 100 m, respectively.
	escalation - domino effects	The fire spread very fast and the flash ball encapsulated the camp site. Tents, cars, caravans etc. were situated very close to each other.
	duration of event sequences	The accident occurred between 2.15 and 2.30 p.m. The explosion and flash fire occurred within about 1 minute. The next 20-30 minutes a violent fire followed the initial flash fire. Motor car tyres, fuel tanks, gas cylinders etc. were ignited due to heat radiation. The fire was under control after two hours and complete extinguished at about 7 p.m. Three chrashes/explosions were registered: the lorry crash to the brick wall; the explosion of the tank; the ignition of the fire ball.
	systems response to events/upsets	-
	operator response to events/upsets	-
	substances formed during the incident	Combustion products of propylene and burning motor car tyres, tents etc.
EMERGENCY SUPPORT	basic ways of controlling/fighting the UFOE(s)	People running from the campsite, fire fighting.
	emergency organisations	The first ambulance was called at about 2.35 p.m. and it arrived at the accident location at about 3.05 p.m. The first fire engine arrived at 3.20 p.m. The accident occurred at an isolated location with about 30 km to the nearest fire station. A central for emergency calls did not exists and there the fire brigade, the ambulance service, the hospitals, the police were called on by one.
	special equipment	The desirability of having primary medical treatment both for minimising suffering and significantly for improving the prognoses for casualties was strongly underlined.
	mitigation systems	-
	escape routes	-
	alarms	-
	inventories	-
	communication lines	-
	lines of command	-

CONTEXT (III)		TRANSPORT BY ROAD Campsite "Los Alfaques"- flash fire and fireball San Carlos de la Rapita; Spain, 11 July 1978
EMERGENCY SUPPORT (continued)	requirements to personnel qualification	-
	contacts to experts	-
	possibilities for an efficient emergency control	Low - a very fast development of the accident course.

TRAINING		TRANSPORT BY ROAD Campsite "Los Alfaques"- flash fire and fireball San Carlos de la Rapita; Spain, 11 July 1978
TRAINING OBJECTIVES	time aspects for on-site operations	The violent accident course occurred within few minutes.
	priority of decisions and actions	First aid, call for emergency, fire fighting.
	critical conditions	Large amount of highly flammable gases.
	constraints on access to incident location	-
	early warning of people	-
	evacuation (transport of injured persons)	Logistical problems of getting emergency services to, and the large numbers of serious casualties from the disaster location.
	measures for environmental protection	-
	operations by internal emergency organisation	-
	operations by external emergency organisations	Fire fighting, transportation of injuries to hospitals, treatment of injuries at hospital.
	fields of responsibilities	-
	communication with the public	-
	co-operation between organisations	-
PARTICIPANTS	trainees	-
	supervisors	-
	evaluators	-
DATA ACQUISITION	logging	-
	observations	-

Reference "Campsite "Los Alfaques"- flash fire and fireball, San Carlos de la Rapita, Spain, 11 July 1978":

Brandsjo, K. (1979). *Eksplosionskatastrofen i Spanien.* Brandværn 3/79, p. 12-19. (In Danish).

Hymes, I. (1985). *Update on the Spanish campsite disaster.* Loss Prevention Bulletin 61, p. 11-16.

APPENDIX I

Transport by rail

Accidents

King's Cross, London - fire (1987, England)
Næstved - release of acrylonitrile (1992, Denmark)

STATUS (I)		TRANSPORT BY RAIL
TERRITORY CHARACTERISTICS	area (e.g. urban, industrial, rural)	urban, industrial, rural
	population density	high, medium, low
	dispersion routes	puffs and plumes by air (combustion products, gaseous release) heavy gases by air (gaseous release) liquids to soil and subsoil water liquids to marine recipients
	meteorological and topographical factors	wind direction and speed, temperature, weather conditions, visibility, darkness, surface roughness, buildings and obstructions
RESOURCES	personnel directly involved in the activity	staff (train and station), passengers
	technical configuration	train: wagons, vessels, cargo materials (containers, drums, sacks etc.) station: lines, passageways, staircases, escalators, entrances, booking offices, ticket boxes, staff accommodation etc.
	amount and number of chemical substances	more than one chemical substance/mixture can be transported by the same rail transport
	construction materials	train: vessels, cargo materials (e.g. steel, plastic) station: wood, steel, glass, plastic, rubber
	electrical supply system	public supply system
	communication system	telephone systems, radio system, signalling equipment, public address system, loudspeaking system, closed circuit television
	transport system	-
PROCESS CONDITION	energy potential	high speed of train
	temperature, high/low	medium
	pressure, high/low	medium
SYSTEMS CONTROL	automation	-
	instrumentation	signal systems train traffic regulated from central operating divisions
	on-line control	-
	process control	-
	operator supervision	engine driver, staff at railway stations, train staff
	safety systems, confinements	tank wagon fire fighting equipment, e.g. water fog system
ORGANISATION	work organisation	railway staff (booking clerks, railmen, station inspector, station manager), train staff, railway operating divisions
	safety organisation	-
SOURCES OF INFORMATION	system documentation	RID-list (information on wagons with dangerous goods) description of the tanker and its structural stability, information on chemical substances and handling of spills
	literature	traffic accident data bases, CEFIC-cards (safety cards for road transport), Handbook for Emergency Response Leaders
	accident descriptions	accident/incident/near misses occurred with different types of wagons and goods accident/incident/near misses concerning passenger transport

STATUS (II)		TRANSPORT BY RAIL
SOURCES OF INFORMATION	information from organisations/consultants	investigations on railway accidents
	information from authorities	information about transportation of dangerous goods, national speed limits legislation concerning fire fighting and emergency preparedness
	validation of information and sources	information up to date, information available
ANALYSIS METHODS	structural aspects	connecting branches for loading and unloading should be standardised; capacity of tank wagons and possible amount of release; use of non-flammable materials; installation of alarms and fire fighting systems
	operational aspects	tolerance of signal system due to human error procedures for cleaning; detailed knowledge about the geography of accident location must be available for the fire brigade
	managerial aspects	alarm messages shall be as correct as possible; precise information about chemical substances must be available; labelling of tank wagons, information on all sides; antidote-preparedness system; training in fire fighting; procedures for informing train/engine drivers in case of emergency; areas of responsibilities

CONTEXT (I)		TRANSPORT BY RAIL
INCIDENT	hazard source	combustible materials, fire spread, large amounts of toxic chemicals
	loss of confinement	ignition of combustible materials, structural damage to tank/vessel/container
	uncontrolled flow of energy (UFOE)	fire, evaporation and dispersion
	potential exposure	smoke, fire effluents, flames, heat conduction, release of toxic substances
VULNERABLE OBJECTS	people threatened in high risk zones	passengers, staff
	people that might be affected	passengers, staff, people living close to the accident location, emergency management personnel
	environmental impacts (recipients)	pollution of marine recipients causing damage to flora and fauna, contamination of soil
	impact on property	damage to goods, train, tracks, stations etc.
	areas affected by the incident (source distance)	in case of fire/explosion about 300-500 m from the accident location pollution of marine recipients may cause long distance effects
SCENARIO	incident mechanisms	ignition of combustible materials, insufficient fire fighting collision, structural damage to tanker, release of chemicals, evaporation
	initiating events/upsets	human error, insufficient maintenance, containment failure

CONTEXT (II)		TRANSPORT BY RAIL
SCENARIO (continued)	external events	traffic problems, weather conditions, insufficient knowledge about the incident and the chemicals released
	event sequences (intermediate events)	-
	escalation - domino effects	harm to people, fire spread, missiles, pollution of vulnerable recipients
	duration of event sequences	can be very short - less than 20 minutes/even momentary - from the initiating event until the release/fire
	systems response to events/upsets	automatic fire alarms at railway stations
	operator response to events/upsets	staff on location may give the first call for an emergency planned/ad hoc operations personnel safety equipment
	substances formed during the incident	smoke (combustion and decomposition products), fire effluents
EMERGENCY SUPPORT	basic ways of controlling/fighting the UFOE(s)	evacuate, establish safety zone, fire fighting, fire prevention, reload chemicals, use absorbing materials, redirect flow away from vulnerable recipients
	emergency organisations	the public fire brigade, the police, the civil defence, the ambulance service, hospitals, Chemical Emergency Service
	special equipment	emergency treatment of people exposed to toxic substances or burns, equipment for personnel protection, equipment for reloading chemicals
	mitigation systems	e.g. transportable basins for collection of water from fire fighting, collection of chemical/oil spills in marine recipients
	escape routes	must be designated at railway stations
	alarms	-
	inventories	amount and type of chemicals in the cargo, layout of railway stations
	communication lines	contacts to leader of the emergency operations, contact to hospitals, contact to the transport company, contact to authorities responsible for environmental protection
	lines of command	-
	requirements to personnel qualification	knowledge about handling and properties of chemical substances
	contacts to experts	specific knowledge about chemicals, poisoning (antidotes) and pollution
	possibilities for an efficient emergency control	primary victims can be difficult to rescue, in case of chemical release to vulnerable recipients severe environmental damage can be difficult to avoid

TRAINING		TRANSPORT BY RAIL
TRAINING OBJECTIVES	time aspects for on-site operations	in case of fire/explosion the accident can escalate within few minutes a fast operation can be needed to limit/avoid release to vulnerable recipients
	priority of decisions and actions	first aid, call for emergency, fire fighting, stop traffic, limit release, redirect flow, warn people, clean up, reload spill
	critical conditions	large amount of flammable/explosive/toxic substances, release rate, ignition source
	constraints on access to incident location	generation of smoke, heat or toxic gases can cause difficulties in order to get access to the incident location
	early warning of people	police
	evacuation (transport of injured persons)	the accident course may develop fast and a fast evacuation is needed logistical problems of getting emergency services to, and the serious casualties from the accident location people living close to the accident location may be asked to remain indoors
	measures for environmental protection	spill combating equipment, containers and equipment for reloading
	operations by internal emergency organisation	call for an emergency, information about substances
	operations by external emergency organisations	fire fighting, evacuation, first aid, transport by ambulances, traffic control, train control, reload the released substances, avoid contamination (soil, marine recipients, ground water), inform the people living close the incident location
	fields of responsibilities	the local fire brigade officer responsible for the emergency operations
	communication with the public	police
	co-operation between organisations	collaboration between the response teams and the railway staff
PARTICIPANTS	trainees	railway safety officers, heads of external emergency organisations, key decision makers
	supervisors	experts from authorities and emergency organisations
	evaluators	representatives from the railway, the line organisations, the authorities, the emergency organisations, training experts
DATA ACQUISITION	logging	computer logs, video/audio tape recording
	observations	working climate, stress factors

STATUS (I)		TRANSPORT BY RAIL King's Cross Underground Fire London, United Kingdom, 18 November 1987
TERRITORY CHARACTERISTICS	area (e.g. urban, industrial, rural)	urban (underground railway station)
	population density	high
	dispersion routes	-
	meteorological and topographical factors	-
RESOURCES	personnel directly involved in the activity	staff (25 people); British Transport Police (4 people); passengers in trains and at the underground station (on an average weekday over 250.000 passengers used the station)
	technical configuration	King's Cross Underground Station: - five lines meet at the underground station which are built at five different levels below ground connected by passageways, staircases and escalators - various entrances to the underground station - booking offices, ticket boxes, staff accommodation etc. Escalators no. 4, 5 and 6: inclined 30 degrees and rose through 17,2 m.
	amount and number of chemical substances	-
	construction materials	- wood (escalator treads, skirting boards, balustrades, advertisement backboards temporary hoarding, temporary station operations room), escalator wheels, paint, grease on running tracks, rubber handrail, plastic advertisements - mass burnt in fire: 3195 kg (all fuels) in escalator shaft 755 kg (all fuels) in ticket hall
	electrical supply system	public supply system
	communication system	two telephone systems, radio system, signalling equipment, public address system, loudspeaking system, closed circuit television
	transport system	-
PROCESS CONDITION	energy potential	heat released during fire: 64357 MJ (all fuels) in escalator shaft 9595 MJ (all fuels) in ticket hall
	temperature, high/low	-
	pressure, high/low	-
SYSTEMS CONTROL	automation	-
	instrumentation	-
	on-line control	-
	process control	-
	operator supervision	staff on duty at KC
	safety systems, confinements	a water fog system was not activated, the relief station inspector knew about the system in general terms but had never used it or seen it used

STATUS (II)		TRANSPORT BY RAIL King's Cross Underground Fire London, United Kingdom, 18 November 1987
ORGANISATION	work organisation	On duty at KC: five booking clerks; one supervisory booking clerk; three railmen all on the tube side (helped passengers with information, assisted with crowd control etc.); eight leading railmen (ticket control); one station inspector; one relief station inspector; one station manager. The nine railway lines were organised into four operating divisions who were responsible for all aspects of the day-to day running of the railway. At the time of the alarm four British Transport Police officers were on patrol in the KC station area.
	safety organisation	- at the senior levels there was no clear definition of responsibility and no auditing - the London Underground rule book required staff to deal themselves with any outbreak of fire whenever possible and only to send for the fire brigade when the fire was beyond their control - no rendezvous points at the station, no briefing of the Fire Brigade by Underground staff when the Fire brigade arrived
SOURCES OF INFORMATION	system documentation	-
	literature	-
	accident descriptions	between 1956 and 1988 there have been 46 escalator fires and 32 instances the cause was attributed to smoker's materials from 1958 to 1987 there were an average of 20 fires per year on escalators and other equipment
	information from organisations/consultants	-
	information from authorities	-
	validation of information and sources	-
ANALYSIS METHODS	structural aspects	a metal cleat which should have prevented matches from falling through the space between the treads and the skirting board was missing, replace wooden escalators with metal ones, use of non-flammable grease, install smoke detectors which automatically switch on water spray
	operational aspects	the running tracks was not cleaned and lubricated regularly detailed knowledge about the geography of station for the fire brigade
	managerial aspects	training in fire fighting, defence in depth (call the fire brigade whenever a fire is detected not just when it seems to get out of control), procedures for informing train drivers in case of emergency, insufficient follow-up after previous fires, clarify areas of responsibilities, accident reporting system

CONTEXT (I)		**TRANSPORT BY RAIL** King's Cross Underground Fire London, United Kingdom, 18 November 1987
INCIDENT	hazard source	combustible materials, fire spread
	loss of confinement	ignition of combustible materials
	uncontrolled flow of energy (UFOE)	fire
	potential exposure	smoke, fire effluents, flames, heat conduction
VULNERABLE OBJECTS	people threatened in high risk zones	31 people died (30 passengers and 1 fireman) many injuries (overcome by smoke, burns)
	people that might be affected	passengers at the stations; passengers in trains; staff; people from emergency organisations
	environmental impacts (recipients)	-
	impact on property	damage to escalators and ticket hall
	areas affected by the incident (source distance)	-
SCENARIO	incident mechanisms	ignition of grease and dust, insufficient fire fighting, two weeks before the disaster, gaps were observed between the treads and the skirting board of the escalator
	initiating events/upsets	a lighted match was dropped by a passenger on escalator 4 which set fire to an accumulation of grease and dust on the running track
	external events	-
	event sequences (intermediate events)	-
	escalation - domino effects	-
	duration of event sequences	19.29 a passenger reported a small fire; 19.30 another passenger saw smoke and he stopped the escalator; 19.30 Relief Station Inspector and a Railman went to the escalator; 19:32 a Police Constable from British Transport Police called his headquarter to summon the London Fire Brigade; 19.33/34 999 call to London Fire Brigade from British Transport Police; 19.35 Relief Station Inspector went into the lower machine room but saw and smelt nothing; 19.38 Relief Station Inspector tried to fight the fire with a carbon monoxide extinguisher; 19.39 the police officers in the ticket hall decided to evacuate the area; 19.40 a Police Constable ordered trains not to stop at KC; 19.42 the first fire engine arrived; 19.42 and 1943 trains stopped at KC; 19.43 flames licking up the handrail of the escalator; 19.44/45: the ticket hall was engulfed in intense heat and thick black smoke; 19.45 flashover; 19.59 first ambulance arrived at KC; 20.16 London Ambulance Service major accident was declared; 20.45 a train stopped at KC; 21.48 fire surrounded; 01.46 fire contained

CONTEXT (II)		**TRANSPORT BY RAIL** King's Cross Underground Fire London, United Kingdom, 18 November 1987
SCENARIO (continued)	systems response to events/upsets	no automatic fire alarms or fire protection
	operator response to events/upsets	the response of the staff was uncoordinated, haphazard and untrained the relief station inspector did not notify the station manager or the line controller as soon as he received a report on fire
	substances formed during the incident	smoke, fire effluents
EMERGENCY SUPPORT	basic ways of controlling/fighting the UFOE(s)	fire prevention, fire fighting, evacuate people
	emergency organisations	London Fire Brigade; Metropolitan Police; London Ambulance Service, 14 ambulances; British Transport Police, 82 officers
	special equipment	water spray available but not activated
	mitigation systems	
	escape routes	not clearly designated
	alarms	no alarms activated automatically, alarm was raised by an officer from British Transport Police
	inventories	-
	communication lines	communication problems: the fire officer at the first appliance was killed and the officers of the other appliances were cut off below ground neither the chief or deputy chief ambulance officers could be reached at the first call
	lines of command	not clear
	requirements to personnel qualification	-
	contacts to experts	-
	possibilities for an efficient emergency control	poor, because: - the staff had not been adequately trained - there was no plan for evacuation of the station - communications equipment was poor or not used - there were no supervision

TRAINING		TRANSPORT BY RAIL King's Cross Underground Fire London, United Kingdom, 18 November 1987
TRAINING OBJECTIVES	time aspects for on-site operations	the flashover occurred within two minutes after the fire brigade arrived at the location
	priority of decisions and actions	first aid, evacuate people, information to trains not to stop at KC, fire fighting
	critical conditions	the flashover was very difficult to anticipate
	constraints on access to incident location	generation of smoke and heat made it impossible to get access to the incident location
	early warning of people	difficult as it was very difficult to anticipate the flashover
	evacuation (transport of injured persons)	-
	measures for environmental protection	-
	operations by internal emergency organisation	-
	operations by external emergency organisations	fire fighting, evacuation, first aid, transport by ambulances, traffic control, train control
	fields of responsibilities	there were no clear definition of responsibility
	communication with the public	-
	co-operation between organisations	-
PARTICIPANTS	trainees	-
	supervisors	-
	evaluators	-
DATA ACQUISITION	logging	-
	observations	-

References "King's Cross Underground Fire, London, United Kingdom, 18 November 1987":

Fennell, D. (1988). *Investigation into the King's Cross Underground Fire,* Department of Transport, London, 248 pp.

Kletz, T.A. (1990). *Critical Aspects of Safety and Loss Prevention (page 193-194),* Butterworths & Co, 349 pp.

STATUS		TRANSPORT BY RAIL Næstved railway accident Næstved, Denmark, 25 September 1992
TERRITORY CHARACTERISTICS	area (e.g. urban, industrial, rural)	urban (railway station)
	population density	high
	dispersion routes	air, ground level
	meteorological and topographical factors	light breeze from SE the railway station is on all sides adjacent to private houses and a bus station
RESOURCES	personnel directly involved in the activity	the engine driver
	technical configuration	tank wagon, goods train transport
	amount and number of chemical substances	67000 litres of acrylonitrile
	construction materials	steel ?
	electrical supply system	-
	communication system	central signalling post, radio communication
	transport system	-
PROCESS CONDITION	energy potential	high speed of train
	temperature, high/low	medium
	pressure, high/low	medium
SYSTEMS CONTROL	automation	-
	instrumentation	-
	on-line control	-
	process control	-
	operator supervision	engine driver
	safety systems, confinements	tank wagon
ORGANISATION	work organisation	-
	safety organisation	-
SOURCES OF INFORMATION	system documentation	RID-list (information on wagons with dangerous goods)
	literature	CEFIC-cards (safety cards for road transport) Handbook for Emergency Response Leaders
	accident descriptions	-
	information from organisations/consultants	-
	information from authorities	-
	validation of information and sources	-
ANALYSIS METHODS	structural aspects	connecting branches for loading and unloading should be standardised capacity of tank wagons and possible amount of release
	operational aspects	tolerance of signal system due to human error
	managerial aspects	alarm messages shall be as correct as possible precise information about chemical substances must be available labelling of tank wagons, information on all sides antidote-preparedness system

CONTEXT (I)		TRANSPORT BY RAIL Næstved railway accident Næstved, Denmark, 25 September 1992
INCIDENT	hazard source	large amounts of toxic chemicals
	loss of confinement	structural damage to tank
	uncontrolled flow of energy (UFOE)	evaporation and dispersion
	potential exposure	release of toxic substances
VULNERABLE OBJECTS	people threatened in high risk zones	the engine driver, people staying at the station, people living close to the station, people from the fire brigade and the civil defence 2 people were injured, 30 persons complained about symptoms such as nausea and dizziness
	people that might be affected	people living in Næstved
	environmental impacts (recipients)	306 m^3 soil and 606 m^3 water were contaminated and removed
	impact on property	damage to goods train and passenger train
	areas affected by the incident (source distance)	safety zone of 200 m
SCENARIO	incident mechanisms	the goods train collided with an empty passenger train; a tank wagon containing 67000 litres acrylonitrile turned over and a leakage from a weld seam arose resulting in a spillage of app. 600 litres
	initiating events/upsets	the engine driver overlooked a signal and the speed of the train was too high when he noticed that the next signal was a stop signal
	external events	-
	event sequences (intermediate events)	-
	escalation - domino effects	-
	duration of event sequences	4.50 am train collision: 4.59 am the fire brigade was called by the police; 5.00 am police and ambulance arrived; 5.08 am fire brigade arrived, information about leaking diesel oil; 5.14 am further fire brigade assistance was requested; 5.17 am identification of leaking substance; 5.20 am information to police and hospital; 5.30 am two injured persons sent to hospital; 5.35 am tank and surrounding blanketed with foam and a wedge of woods and sealing compound were put into the untight weld but not a complete tightening; 6.02 am Chemical Emergency Response Service called; 6.13 am environmental authorities called; 6.15 am three possible exposed people sent to hospital; 6.35 am assistance from the civil defence was requested; a 100 m safety zone established; 6.44 am the brigade officer received wagon information from the Danish Railways (DSB); 7.00 am the public informed about the accident; 7.10 am the hospital called the national poison information centre about antidotes; 11.45 am the hospital received the antidote; late in the evening fire fighters from Bayer AG arrived reloading was started which lasted all the night; a 200 m safety zone was established

CONTEXT (II)		TRANSPORT BY RAIL Næstved railway accident Næstved, Denmark, 25 September 1992
SCENARIO (continued)	systems response to events/upsets	a railwayman on the platform gave the alarm
	operator response to events/upsets	-
	substances formed during the incident	acrylonitrile
EMERGENCY SUPPORT	basic ways of control-ling/fighting the UFOE(s)	cover with foam, establish safety zone
	emergency organisations	the public fire brigade, the police, the civil de-fence, the ambulance service, Næstved hospital, the Chemical Engineering Emergency Service
	special equipment	vehicles with water tanks and foam equipment; gas-proof chemical clothing; breathing appara-tus; wedges of wood an sealing compound, gas detectors; containers and equipment for reloading RID-list (information on wagons with dangerous goods) CEFIC-cards (safety cards for road transport) Handbook for Emergency Response Leaders
	mitigation systems	-
	escape routes	-
	alarms	-
	inventories	-
	communication lines	DSB called the police and the Emergency Service the public fire brigade was called by the police Næstved county hospital was informed by the police
	lines of command	-
	requirements to personnel qualification	knowledge about antidote-preparedness the fire brigade should be acquainted with tank wagon construction
	contacts to experts	the national poison information centre (about antidotes)
	possibilities for an efficient emergency control	good

TRAINING		TRANSPORT BY RAIL Næstved railway accident Næstved, Denmark, 25 September 1992
TRAINING OBJECTIVES	time aspects for on-site operations	if the acrolynitrile had been released rapidly or ignited the situation had been very serious demanding a very fast operation by the response teams
	priority of decisions and actions	limit evaporation, limit leakage and release, identify chemical, provide antidote, first aid, reload chemicals, cleaning of contaminated personnel, clean up contaminated soil and water
	critical conditions	release rate, ignition source, amount of chemical substances
	constraints on access to incident location	none
	early warning of people	the public was informed about 2 hours after the incident had occurred
	evacuation (transport of injured persons)	no evacuation people living in the 200 m safety zone was informed by the police to remain indoors
	measures for environmental protection	containers and equipment for reloading
	operations by internal emergency organisation	call for an emergency, information about substances
	operations by external emergency organisations	handling of the emergency situation
	fields of responsibilities	fire brigade officer responsible for the emergency operations
	communication with the public	no information prior to the accident the public received incident information via radio and newspapers
	co-operation between organisations	the collaboration between the response teams and the staff of DSB was satisfactory
PARTICIPANTS	trainees	-
	supervisors	-
	evaluators	-
DATA ACQUISITION	logging	-
	observations	-

Reference "Næstved railway accident, Næstved, Denmark, 25 September 1992":

Gronberg, C.D. et al. (1993). *Lessons Leant from Emergencies after Accidents in Denmark Involving Dangerous Substances.* Riso-I-702(EN). 59 pp.

APPENDIX J

Natural disasters

Accidents

Awaji Island - earthquake (1995, Japan)
Leaward Island - hurricane (1989, Caribbean)

STATUS		NATURAL DISASTER
TERRITORY CHARACTERISTICS	area (e.g. urban, industrial, rural)	urban, industrial, rural
	population density	high, medium, low
	dispersion routes	-
	meteorological and topographical factors	-
RESOURCES	personnel directly involved in the activity	-
	technical configuration	-
	amount and number of chemical substances	-
	construction materials	-
	electrical supply system	-
	communication system	
	transport system	-
PROCESS CONDITION	energy potential	high
	temperature, high/low	high/low (e.g. volcanic eruption, blizzard)
	pressure, high/low	-
SYSTEMS CONTROL	automation	-
	instrumentation	-
	on-line control	-
	process control	-
	operator supervision	-
	safety systems, confinements	-
ORGANISATION	work organisation	-
	safety organisation	disaster preparedness (regional, national, international), emergency organisations (police, fire brigade, civil defence, hospitals, ambulance etc.)
SOURCES OF INFORMATION	system documentation	-
	literature	theories on natural disaster (forecasting, frequency, target areas, development etc.,)
	accident descriptions	descriptions of natural disasters and emergency preparedness
	information from organisations/consultants	research institutes/universities, disaster preparedness and prevention organisation
	information from authorities	ministries, civil defence, military, hospitals, fire brigade, police, ambulance service
	validation of information and sources	information available, information up to date
ANALYSIS METHODS	structural aspects	the ratio of visible to invisible damage; the size of the impact area and the severity of impact; availability and maintainability of designated emergency equipment
	operational aspects	cooperation between cadre and volunteers; availability of written procedures for accessing and detailing the emergency response
	managerial aspects	response time and optimal performance; major sub-event crises triggered by the event; the degree of psychological distortion caused by the impact of the event; information flow; decision making; strategic preparedness translating meta-strategic missions and objectives into operational strategies; post-impact procedures and planning

CONTEXT (I)		NATURAL DISASTER
INCIDENT	hazard source	natural force
	loss of confinement	structural damage, subsidence, liquefaction
	uncontrolled flow of energy (UFOE)	hurricane, earthquake, flood, avalanche, volcanic eruption etc.
	potential exposure	conflagration, structural damage, collapse of residential dwellings, high wind speed collapse of houses etc.
VULNERABLE OBJECTS	people threatened in high risk zones	people living/staying in the target area the disaster can cause a huge number of fatalities and serious injuries
	people that might be affected	people from the emergency organisation, volunteers
	environmental impacts (recipients)	damage to large areas, e.g. volcanic eruption
	impact on property	destruction of a huge amount of buildings, dwellings, houses, infrastructure etc. destruction to supply systems (clean water, electricity, gas, drain etc.)
	areas affected by the incident (source distance)	large areas (possible regions/countries) may be affected
SCENARIO	incident mechanisms	hurricane, earthquake, flood, avalanche, volcanic eruption etc.
	initiating events/upsets	-
	external events	-
	event sequences (intermediate events)	-
	escalation - domino effects	damage to/destruction of buildings, dwellings, houses, infrastructure etc.
	duration of event sequences	the disaster event may occur fast but the emergency protective actions (evacuation, transport of injuries, fire fighting, dam construction etc.) will often be necessary for several days/weeks
	systems response to events/upsets	quick turn-out of emergency response teams to co-ordinate the emergency response and resources, request for additional assistance from regional/national emergency organisation /forces, cordon of main roads (traffic control)
	operator response to events/upsets	-
	substances formed during the incident	-
EMERGENCY SUPPORT	basic ways of controlling/fighting the UFOE(s)	evacuate people from target area, monitoring/forecasting programmes, limit fire spreading, limit floods (dams), provide supplies (clean water, food, medicine, tents, blankets etc.)
	emergency organisations	fire brigade, hospitals, ambulance service, police, military, ministries, specific disaster preparedness and prevention organisation/institutes
	special equipment	emergency supplies in private homes in high risk areas, fire fighting units capable of bringing adequate resources into an environment that sustain infrastructure damage, monitoring/forecasting equipment

CONTEXT (II)		NATURAL DISASTER
EMERGENCY SUPPORT (continued)	mitigation systems	-
	escape routes	-
	alarms	-
	inventories	-
	communication lines	establishment of a lead agency for the emergency management for co-ordination of communication and decisions
	lines of command	-
	requirements to personnel qualification	operational management triage (response managers and their teams need to feel that they apply a justified system to face critical decisions in terms of who is first attended and who have to be left alone, they need training not only in doing so but also in coping with the mental and moral implications involved)
	contacts to experts	specific knowledge about the natural force in question (e.g. forecasting), experience from other disaster situations and emergency actions
	possibilities for an efficient emergency control	the number of losses (fatalities, injuries) and loss of resources will depend on the strategic preparedness and practical experiences of the response organisations

TRAINING (I)		NATURAL DISASTER
TRAINING OBJECTIVES	time aspects for on-site operations	a fast response time is needed at several locations at the same time important to obtain a clear identification of response needs: number of victims, damage to houses etc.
	priority of decisions and actions	identification of response needs, evacuation of injuries (who is first attended and who have to be left alone, possible to die), first aid, fire fighting, procure resources (food, medicine, water, tents etc.), building up/stabilising dwellings and infrastructure
	critical conditions	escalation (e.g. fires, floods) structural damage (e.g. collapse of residential dwellings)
	constraints on access to incident location	damage to infrastructure and buildings, entrapped victims
	early warning of people	monitoring programme for disaster forecasting
	evacuation (transport of injured persons)	transport of a huge number of moderately to seriously injured people displacement of a huge number of people staying/living in the target area
	measures for environmental protection	-
	operations by internal emergency organisation	-

TRAINING (II)		NATURAL DISASTER
TRAINING OBJECTIVES (continued)	operations by external emergency organisations	evacuation, transport, first aid, fire fighting, procure resources, building up/stabilising dwellings and infrastructure, establishment of relief distribution systems, co-ordination of the emergency response (needs and resources available)
	fields of responsibilities	-
	communication with the public	police, ministries
	co-operation between organisations	national, regional and international emergency organisations
PARTICIPANTS	trainees	heads of emergency organisations, key decision makers, experts on natural forces and natural disasters
	supervisors	training experts, disaster management experts
	evaluators	representatives from the authorities, the emergency organisations, specific disaster preparedness and prevention organisation/institutes, training experts
DATA ACQUISITION	logging	computer logs, video/audio tape recordings
	observations	working climate, stress factors

STATUS		NATURAL DISASTERS Earthquake Kobe, Awaji Island, Japan, 17 January 1995
TERRITORY CHARACTERISTICS	area (e.g. urban, industrial, rural)	urban
	population density	high (population 1,5 million, Kobe is the second largest port in Japan)
	dispersion routes	-
	meteorological and topographical factors	-
RESOURCES	personnel directly involved in the activity	-
	technical configuration	-
	amount and number of chemical substances	-
	construction materials	-
	electrical supply system	-
	communication system	-
	transport system	-
PROCESS CONDITION	energy potential	high
	temperature, high/low	-
	pressure, high/low	-
SYSTEMS CONTROL	automation	-
	instrumentation	-
	on-line control	-
	process control	-
	operator supervision	-
	safety systems, confinements	-
ORGANISATION	work organisation	-
	safety organisation	-
SOURCES OF INFORMATION	system documentation	-
	literature	-.
	accident descriptions	-
	information from organisations/consultants	-
	information from authorities	fire brigade, police, military, ministries
	validation of information and sources	-
ANALYSIS METHODS	structural aspects	the ratio of visible to invisible damage, the size of the impact area and the severity of impact
	operational aspects	cooperation between cadre and volunteers
	managerial aspects	response time and optimal performance of the emergency managers; the number of major sub-event crises triggered by the impact of the event; the degree of psychological distortion caused by (or accelerated by) the impact of the event; information flow; decision making; strategic preparedness translating meta-strategic missions and objectives into operational strategies that are realistic and achievable

CONTEXT (I)		NATURAL DISASTERS Earthquake Kobe, Awaji Island, Japan, 17 January 1995
INCIDENT	hazard source	natural force
	loss of confinement	subsidence and liquefaction
	uncontrolled flow of energy (UFOE)	earthquake, motion
	potential exposure	conflagration, structural damage, collapse of residential dwellings
VULNERABLE OBJECTS	people threatened in high risk zones	people staying in the vicinity of the epicentre (Kobe some 24 km from the epicentre) 5000 people died 25000 moderately to seriously injured
	people that might be affected	people from the emergency organisations
	environmental impacts (recipients)	-
	impact on property	46000 buildings destroyed; 1000000 people were without clean water; 800000 people were without gas supplies; over 100 major fires; 500 metres of the elevated Hanshin Highway did collapse; 8 major fractures in the rail tracks of the Shinkansen bullet train
	areas affected by the incident (source distance)	heavy damage to structures occurs up to 70 km from Awaji Island (approximately 2000 km^2
SCENARIO	incident mechanisms	earthquake (the earthquake measured 7,2)
	initiating events/upsets	-
	external events	-
	event sequences (intermediate events)	quake → fire (hundreds of separate blazes) → water mains failed (damage or dislocation of infrastructure supply of water and electricity) → response vehicles failed to arrive at any particular sub-event site
	escalation - domino effects	-
	duration of event sequences	-
	systems response to events/upsets	immediately after the quake Kobe authorities failed to cordon off main roads for official use and the delay of police and fire vehicles undoubtedly raised the death toll; for nearly four hours the Governor of Hyogo prefecture neglected to make the necessary request for aid to the national armed forces (the reason for this may reside in the cultural aspects of organisations and communities, conventional Japanese bottom-up decision-making styles impede central executive decisions and require more time in which to arrive at decisions); poor interaction between the civil and military authorities in the Kobe-Hyogo region and lack of interaction between ministries contributed to loss of time in responding to the impact of the earthquake
	operator response to events/upsets	-
	substances formed during the incident	-

CONTEXT (II)		NATURAL DISASTERS Earthquake Kobe, Awaji Island, Japan, 17 January 1995
EMERGENCY SUPPORT	basic ways of controlling/fighting the UFOE(s)	evacuate people, limit fire spreading, provide supplies (water, food, medicine etc.)
	emergency organisations	fire brigade, hospitals, ambulance service, police, military, ministries
	special equipment	emergency supplies in private homes (in Tokyo 27% kept emergency supplies, in Osaka only 2,6%); fire fighting units capable of bringing adequate resources into an environment that sustained infrastructure damage
	mitigation systems	-
	escape routes	-
	alarms	-
	inventories	-
	communication lines	signs of communication failure and lack of direction and the need to exert undue effort and costs in time in order to communicate
	lines of command	unclear lines of management escalation with consequent lack of integrated deployment of all available resources
	requirements to personnel qualification	operational management triage (response managers and their teams need to feel that they apply a justified system to face critical decisions in terms of who is first attended and who have to be left alone, they need training not only in doing so but also in coping with the mental and moral implications involved)
	contacts to experts	-
	possibilities for an efficient emergency control	poor (Kobe might have emerged from the earthquake with fewer casualties and loss of resources if the response organisations had developed concepts and practices of strategic preparedness)

TRAINING (I)		NATURAL DISASTERS Earthquake Kobe, Awaji Island, Japan, 17 January 1995
TRAINING OBJECTIVES	time aspects for on-site operations	a fast response time is needed at several locations at the same time
	priority of decisions and actions	who is first attended and who have to be left alone, possible to die fire fighting procure food, medicine, water, tents etc. building up/stabilising dwellings and infrastructure
	critical conditions	escalation of fires collapse of residential dwellings
	constraints on access to incident location	damage to infrastructure and buildings, entrapped victims
	early warning of people	-
	evacuation (transport of injured persons)	25000 moderately to seriously injured

TRAINING (II)		NATURAL DISASTERS Earthquake Kobe, Awaji Island, Japan, 17 January 1995
TRAINING OBJECTIVES (continued)	measures for environmental protection	-
	operations by internal emergency organisation	-
	operations by external emergency organisations	evacuation, transport, first aid, fire fighting, procure resources, building up/stabilising dwellings and infrastructure
	fields of responsibilities	-
	communication with the public	-
	co-operation between organisations	-
PARTICIPANTS	trainees	-
	supervisors	-
	evaluators	-
DATA ACQUISITION	logging	-
	observations	-

Reference "Earthquake, Kobe, Awaji Island, Japan, 17 January 1995":

Heath, R. (1995). *The Kobe earthquake: some realities of strategic management of crises and disasters*, Disaster Prevention and Management, volume 4, number 5, p 11-24.

STATUS		NATURAL DISASTER Hurricane Hugo Leeward, Caribbean, 16-19 September 1989
TERRITORY CHARACTERISTICS	area (e.g. urban, industrial, rural)	urban, industrial, rural
	population density	high, medium, low
	dispersion routes	-
	meteorological and topographical factors	wind speed in excess of 150 mph
RESOURCES	personnel directly involved in the activity	-
	technical configuration	-
	amount and number of chemical substances	-
	construction materials	-
	electrical supply system	-
	communication system	-
	transport system	-
PROCESS CONDITION	energy potential	high
	temperature, high/low	-
	pressure, high/low	-
SYSTEMS CONTROL	automation	-
	instrumentation	-
	on-line control	-
	process control	-
	operator supervision	-
	safety systems, confinements	-
ORGANISATION	work organisation	-
	safety organisation	-
SOURCES OF INFORMATION	system documentation	-
	literature	-
	accident descriptions	-
	information from organisations/consultants	-
	information from authorities	-
	validation of information and sources	-
ANALYSIS METHODS	structural aspects	in many instances, the areas designated as National Emergency Operation Centres was being used for other purposes, where the space was still available the appropriate equipment, stationery and facilities were missing or inadequate
	operational aspects	the operation suffered from the absence of clear written co-ordination procedures structuring the accessing and detailing of the response
	managerial aspects	at the national emergency planning systems level there was an absence of post-impact guidelines and in the immediate aftermath of the disaster there was a noticeable lacuna in decision-making which was mitigated by the early arrival of regional and international response teams

CONTEXT (I)		NATURAL DISASTER Hurricane Hugo Leeward, Caribbean, 16-19 September 1989
INCIDENT	hazard source	natural force
	loss of confinement	structural damage
	uncontrolled flow of energy (UFOE)	high wind speed
	potential exposure	collapse of houses, high wind speed
VULNERABLE OBJECTS	people threatened in high risk zones	people living in the target area, emergency organisations; 7 people died; 20000-30000 people displaced
	people that might be affected	-
	environmental impacts (recipients)	-
	impact on property	hundreds of houses totally destroyed. thousands moderate to severe damaged; agriculture crops damaged; thousands of dead of cattle; telephone, electricity and water distribution services disrupted; extensive damage to sugar factories; extensive damage to infrastructure
	areas affected by the incident (source distance)	northern Gaudeloupe, south of Antigua, Redonda, Nevis, St. Kitts, St. Barts, Statia, St. Maarten, Anguill, the British Virgin Islands, Puerto Rico, Charlotte, South Carolina
SCENARIO	incident mechanisms	hurricane
	initiating events/upsets	-
	external events	-
	event sequences (intermediate events)	-
	escalation - domino effects	-
	duration of event sequences	duration of the hurricane was a couple of days emergency operations were performed during a couple of weeks within 24 hours a damage surveillance team had visited Antigua, Montserrat and St. Kitts within 36 hours a clear identification of response needs was provided to regional and international agencies
	systems response to events/upsets	PCDPPP began monitoring the tropical system on September 11; PCDPPP contacted all the islands in the projected trajectory of the system; two response teams were prepositioned in the Eastern Caribbean
	operator response to events/upsets	-
	substances formed during the incident	-

CONTEXT (II)		**NATURAL DISASTER** Hurricane Hugo Leeward, Caribbean, 16-19 September 1989
EMERGENCY SUPPORT	basic ways of controlling/fighting the UFOE(s)	monitoring program for hurricane forecasting, evacuate people from the target area
	emergency organisations	Pan Caribbean Disaster Preparedness and Prevention Project (PCDPPP); United Nations Development Programme (UNDP); Government of the Caribbean Community (CARICOM); CARICOM Disaster Relief Unit (CDRU)
	special equipment	-
	mitigation systems	-
	escape routes	-
	alarms	-
	inventories	-
	communication lines	a lead agency for the emergency management was established in Antigua which was focus for radio communication
	lines of command	-
	requirements to personnel qualification	-
	contacts to experts	many of the personnel participating in the damage assessment and response teams had also operated in the Gilbert hurricane disaster in Jamaica 1988
	possibilities for an efficient emergency control	good

TRAINING (I)		**NATURAL DISASTER** Hurricane Hugo Leeward, Caribbean, 16-19 September 1989
TRAINING OBJECTIVES	time aspects for on-site operations	important to obtain a clear identification of response needs: number of victims, damage to houses etc.
	priority of decisions and actions	identification of response needs, evacuation of injuries, first aid, procure resources, build-up infrastructure
	critical conditions	-
	constraints on access to incident location	damage to infrastructure and buildings, entrapped victims
	early warning of people	monitoring program for hurricane forecasting
	evacuation (transport of injured persons)	20000-30000 people displaced
	measures for environmental protection	-
	operations by internal emergency organisation	-

TRAINING (II)		NATURAL DISASTER Hurricane Hugo Leeward, Caribbean, 16-19 September 1989
TRAINING OBJECTIVES (continued)	operations by external emergency organisations	the military teams of the CDRU provided the initial response team in the affected islands of Antigua, Montserrat, St. Kitts and Nevis, they cleared the roads and assisted in the establishment of relief distribution systems in these islands PCDPPP was co-ordinating and chairing response meetings which were held on daily basis for two weeks (verifying requests from the affected islands and receiving daily reports of the island's needs), CDRU coordinated all of the regional and response teams and resources
	fields of responsibilities	-
	communication with the public	-
	co-operation between organisations	national, regional and international emergency organisations
PARTICIPANTS	trainees	-
	supervisors	-
	evaluators	-
DATA ACQUISITION	logging	-
	observations	-

Reference "Hurricane Hugo, Leeward, Caribbean, 16-19 September 1989":

Collymore, J. (1992), *Hurricane Hugo - A Multi-Islands Disaster: Further Lessons for the Caribbean,* Disaster Management, volume 2, number 3, p 163-167.

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Title and authors

Accident knowledge and emergency management

Birgitte Rasmussen, Carsten Grønberg

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Abstract (max. 2000 characters)

The report contains an overall frame for transformation of knowledge and experience from risk analysis to emergency education.

An accident model has been developed to describe the emergency situation. A key concept of this model is uncontrolled flow of energy (UFOE), essential elements are the state, location and movement of the energy (and mass). A UFOE can be considered as the driving force of an accident, e.g., an explosion, a fire, a release of heavy gases. As long as the energy is confined, i.e. the location and movement of the energy are under control, the situation is safe, but loss of confinement will create a hazardous situation that may develop into an accident.

A domain model has been developed for representing accident and emergency scenarios occurring in society. The domain model uses three main categories: status, context and objectives. A domain is a group of activities with allied goals and elements and ten specific domains have been investigated: process plant, storage, nuclear power plant, energy distribution, marine transport of goods, marine transport of people, aviation, transport by road, transport by rail and natural disasters. Totally 25 accident cases were consulted and information was extracted for filling into the schematic representations with two to four cases pr. specific domain.

Descriptors INIS/EDB

ACCIDENTS; COMMUNICATIONS; COMPLIANCE; DECISION MAKING; EMERGENCY PLANS; NUCLEAR POWER PLANTS; ORGANIZATIONAL MODELS; RISK ASSESSMENT; SAFETY ANALYSIS

Available on request from Information Service Department, Risø National Laboratory, (Afdelingen for Informationsservice, Forskningscenter Risø), P.O.Box 49, DK-4000 Roskilde, Denmark. Telephone +45 46 77 46 77, ext. 4004/4005, Telex 43 116, Telefax +45 46 75 56 27