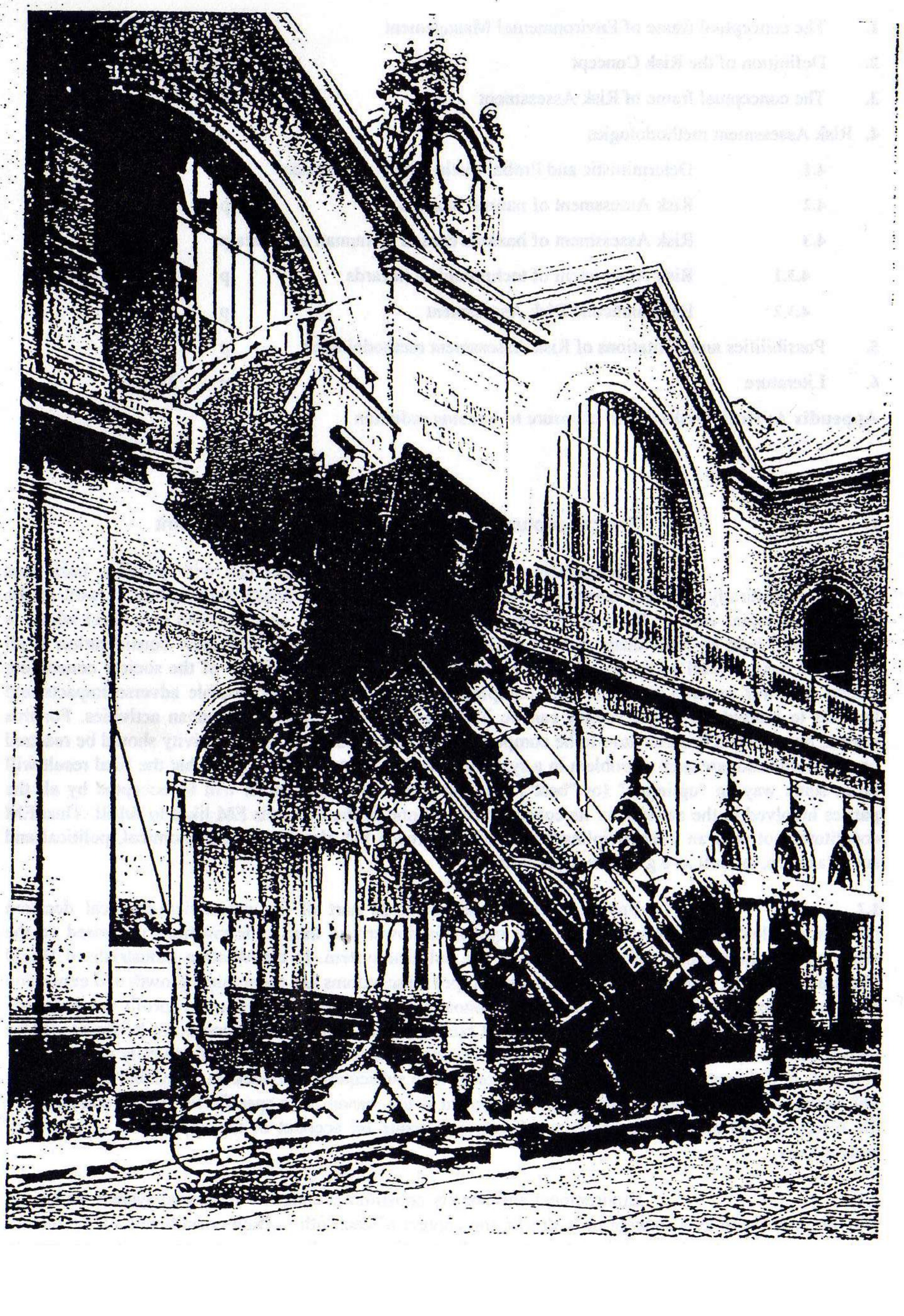
Risk Assesment

A Reader



Risk Assessment - A Reader

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Introduction

Risk assessment techniques were first used by the nuclear power industry more than 50 years ago.

Risk assessment studies start by identifying the full spectrum of plant operating events, including events not considered in current regulations. Using the database compiled from plant experience, along with scientific methods for estimating rare plant operating occurrences, the likelihood of nuclear power plant events can be calculated. Potential events include the rupture of a pipe, failure of an electrical system, or any other of literally thousands of "initiating events"-that is, events that might challenge a plant's safety systems.

The next step in the assessment is the construction of a unique computer model for each nuclear plant. The model combines the initiating event data with the performance data for plant systems that are important to safety. Using standard techniques of statistics and probability, thousands of potential accident sequences are modelled, involving practically every combination of equipment failures imaginable.

Critical worker actions also are analysed, and the likelihood of human error is calculated in the model. The overall approach is called "probabilistic safety analysis," most. nuclear power plants have performed these analyses.

Risk analysis techniques have been reviewed by national laboratories and other independent entities, including the worldwide academic community. The analyses techniques have been improved and refined based on this input. In addition, the analyses for individual nuclear plants have been subjected to peer review. The results of the analyses are estimates, but they are state-of-the-art assessments of nuclear plant safety.

Risk assessment techniques provide a quantitative estimate of reactor safety and a basis for comparison to other risks we face.

The nuclear power industry developed most of the risk assessment tools and techniques used today. These methods of risk assessment are described in detail in this reader. The discussion about the health risks of the operation of these plants are given in the appendix.

All of these methods can be applied to any problems where risks occur. That makes this reader an universal source for risk assessment in the environmental sciences.

Despite all of the risk assessment tools and methods, it happened. On 25th of April 1986, the biggest man made disaster :

"Twenty Years After the Chernobyl Accident
by IAEA Director General Dr. Mohamed ElBaradei

The April 1986 accident at the Chernobyl nuclear power plant remains a painful memory in the lives of the hundreds of thousands of people who were most affected by the accident. In addition to the emergency rescue workers who died, thousands of children contracted thyroid cancer, and thousands of other individuals will eventually die of other cancers caused by the release of radiation. Vast areas of cropland, forests, rivers and urban centres were contaminated by environmental fallout. Hundreds of thousands of people were evacuated from these affected areas - forced to leave behind their homes, possessions, and livelihoods - and resettled elsewhere, in a traumatic outcome that has had long-lasting psychological and social impacts."….(**from IAEA Statements 2006**)

The authors of this reader did find that the Chernobyl accident had effects on early infant mortality rates in Germany ("Early Infant Mortality in West Germany before and after the Chernobyl Accident", The Lancet, **No. 11,**1989, p. 1081-1083,). We where involved in one research project about the consequences for the clean-up-workers "Retrospective Methods of Dose Assessment of the Chernobyl "Liquidators". A Comparison", Proceedings of the IRPA Symposium on Radiation Protection in Neighbouring Countries of Central Europe, Editor Jozef Sabol, Prague 1997,p 309-313.)

If we look at risks given by new technologies, like offshore windpower, we can always compare these risks with the consequences we saw from the Chernobyl accident. To prevent events like those in Chernobyl a deeper inside into risk assessment is needed for young scientists. It is one of the aims of this course, the course handbook and the reader to equip students with the necessary skills to help to prevent disasters. We wish you an interesting study time on this course.

Michael Schmidt Heiko Ziggel

1. The conceptual frame of Environmental Management

1.1 Environmental Management (EM) is conceded with possible hazardous impacts of naturally occurring events or human activities on human health and welfare as well as the society and social values. The overall objective of EM is to reduce specific risks to a level which is "acceptable", both by individuals and the society as a whole, in relation and under consideration of all identified risks as well as the existing resented capabilities and possibilities of the society concerning efforts to lower or even to avoid risks completely. In most cases both possible adverse impacts and benefits to individuals or the society can be identified as a consequence of human activities. For this reason, benefits and hazards have to be compared to decide whether a specific activity should be realized or not. To investigate such a problem in a systematic and understandable way, so that the final result will be in some way an "optimum" (or "best") solution to the problem, which will be accepted by all the parties involved in the activity, or its consequences, is one of the demands EM likes to fulfill. Thus EM constitutes not only an interdisciplinary scientific approach but also involves economical, political and social aspects, as well as e.g. psychological ones. Environmental Management as part of the economical-political decision process is linked to the prevailing political System in power and thus its foundations are based on the same (non scrutinize able) axioms as those of the political System. In the Western Industrialized World (Australia, Canada, Japan, USA and Western Europe) these axioms are economical growth and expansion and profit maximization, On the other side, economical growth and expansion and profit maximization are resented by the condition that the basis of human life and the society should not be threatened by human activities, as e.g. by pollution of the environment, complete exhaustion of naturally occurring raw materials or deforestation of the tropical rain forest with subsequent feedback on the global climate. This link between EM and the prevailing political System is the reason for a specific restriction connected to the results of EM analyses: predictions of resented value on account of the application of unproved assumptions.

1.2 Environment and society constitute a complex dynamical System which can only be understand as a concept of reality in the context of each other. Both constituents of the overall System are connected by a chain of events and activities as well as consequences and measures to chain of events and activities as well as consequences and measures to overcome these consequences. In Fig.1 the overall system is

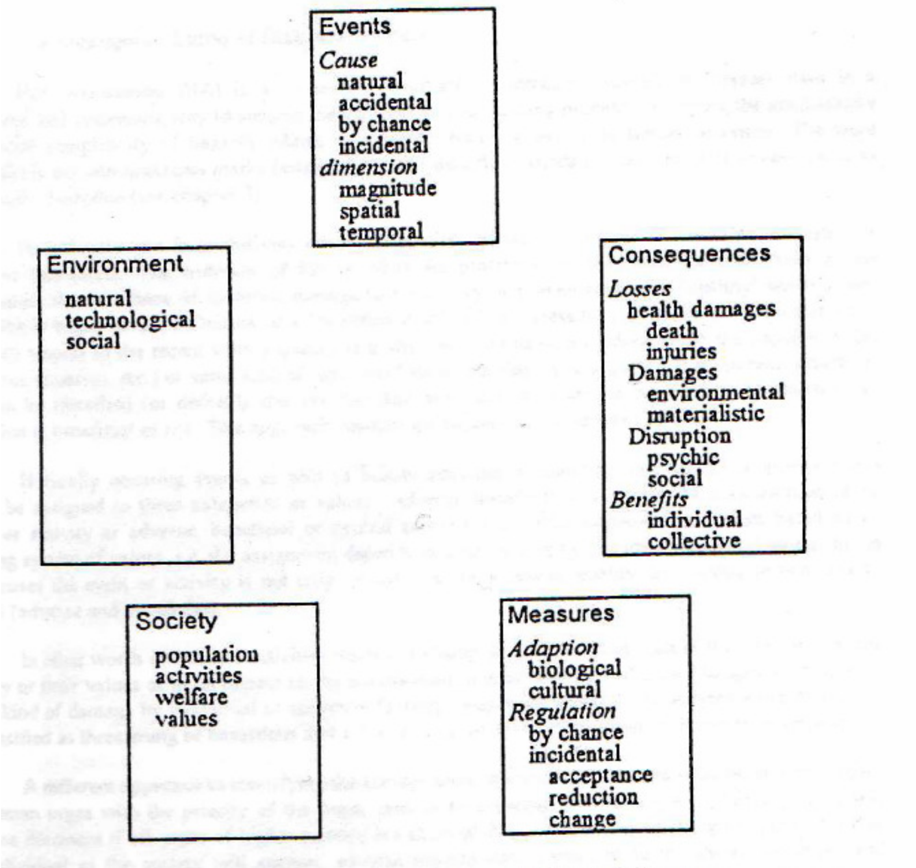

Fig. 1.1: Environment and society as constituents of an overall dynamical system.

depictedpicted.

1.4 The structural scheme of Environmental Management is shown in fig. 1.2. In a first Step the problem has to be identified and defined properly. This involves different aspects: the spatial dimension of the problem (local, regional, national, global); the temporal dimension of the problem (recent or nature consequences); the kind of the problem (emission of harmful substances, social changes, consumption of resources, occupation of ecologically valuable countryside, etc.). For this purpose information has to be collected concerning, both the intended kind of activity and the resulting consequences. The result of this last step is the definition of objectives the intended activity has to fulfill. In the next step possible actions will be identified and analyzed, i.e. all consequences of the intended activity will be investigated and assessed. Additionally to the proposed design and way of implementation of the intended activity alternative designs and ways of implementation will also be investigated and assessed to decide which will be the "best" alternative; in that way that the "benefit" is a maximum and the "damage" is a minimum. In a third step a plan will be prepared to implement the intended activity with consideration of both the short and the long-term consequences. Afterwards the plan will be implemented. Here institutions, responsible for controlling of keeping the rules and Standards in effect have to be nominated and their duties and rights have to be defined accurately. In the last step, after the activity has been implemented, the actual consequences will be evaluated and compared to the predicted effects of the activity; if these last are different adjusting actions have to be considered.

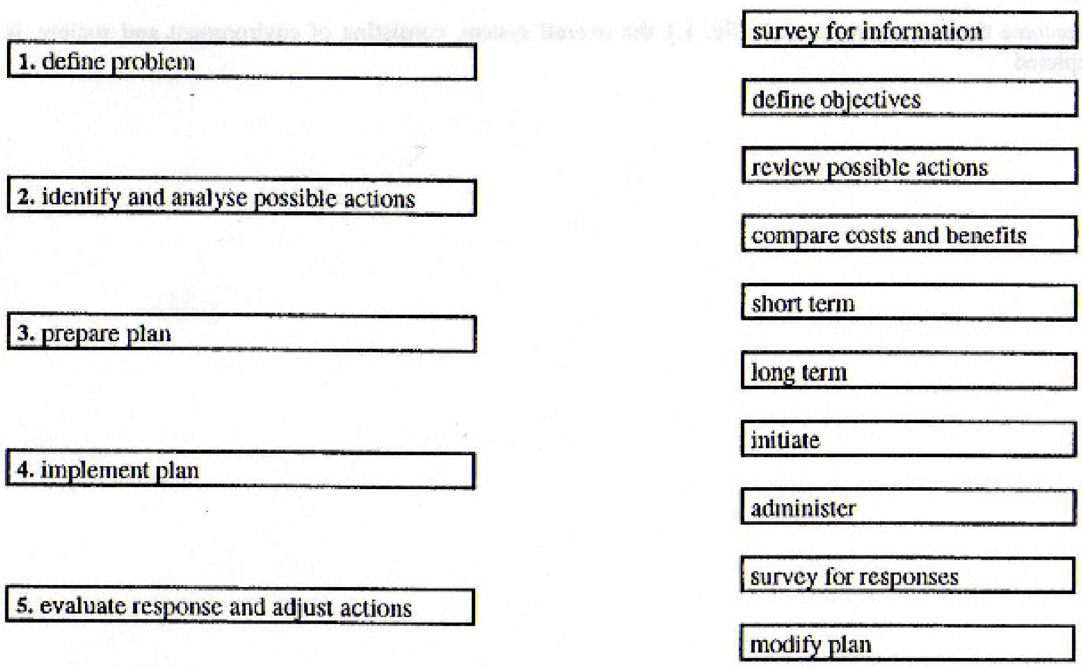

Fig. 1.2: Structural scheme of Environmental Management.

1.5 Environmental Management as a Meta-Structure provides for the identification and assessment of recent and future hazards to the environment, humans and the society. It also allows one to come to an "optimal" decision in the political decision finding process concerning human activities with possibly dangerous consequences against the background of controversial interests advocated by different social groups. It also integrates a number of different "scientific" approaches of hazards identification and evaluation (see fig. 1.3). Each of these approaches can only be understand and used in the context of the overall scheme of EM, since the "scientific" contribution (hazard identification and evaluation) constitutes only one part; economical, political and social aspects have also to be considered in the decision finding process. Thus, the importance of "science" should not be overestimated.

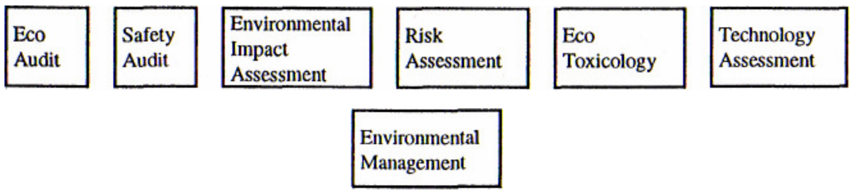

Fig. 1.3: "Scientific" methods of hazard identification and assessment used by Environmental Management.

2.Definition of the Risk Concept

2.1 Risk is a theoretical concept to describe both the probability of occurrence of a particular event and the magnitude (or significance) of its consequence. Most often only adverse consequences of activities will be considered if risks are investigated. Thus, risk is defined as follows:

risk =
probability of occurrence of a particular event * severity of its consequence.

2.2 Besides this formal definition there are different meanings of the term "risk" in use. The term "risk" is well known in economies, engineering, philosophy, politics, psychology and social sciences with always different meanings. Furthermore, there is a general interpretation of the term risk related to the existence of a possible damage. Risk and danger most often are used as synonyms to describe a Situation, which is considered as unsafe. Nevertheless, risk not only wants to describe that something will happen (probability of occurrence of a particular event) but also wants to mention what will be the consequence if something happens.

2.3 The term risk emerged in the 14th - 15th Century when trading with other continents changed from being a cooperative to an individual business. In former days, when goods were sent by ships to other continents, in the case that the ship sunk and the goods were lost, not a single individual but a whole group paid for the damage. This was a first kind of insurance. In time, trading became more and more the activity of single individuals who were now also looking for some kind of insurance in case they lost their goods. This was the time insurances in the form they are known today, entered the stage. Their task was to prevent a trading Company being ruined by losing everything by paying some money to them in this case. On the other band, the Company had to pay some money to the insurance Company even if they lost no goods.

2.4 The concept of risk can be defined with respect to all human activities, naturally occurring events, incidents and accidents of technological facilities and Systems. To calculate a risk the precise definition of the adverse effect under investigation is required; risk only has its meaning with respect to a particular damage. Risks concerning damage to humans can be defined with respect to single individuals or a group; in the first case the term individual risk is used, in the latter case the term collective risk. The collective risk is defined by the probability distribution of the expected number of realizations of a specified outcome of an activity in a population and by the size of the population. The individual risk of being affected by a specific damage is the collective risk corrected by consideration of the specific behavior of the individual. In both cases specific risks as well as the total risk related to an activity or facility can be calculated. The concept of specific risk implies that it is possible to differentiate between different realization of damages, to quantify the contribution of the specified condition with respect to the specified damage/risk and to separate this contribution from the contribution of all other conditions resulting in the same damage.

2.5 Risks can be estimated absolutely or relatively. When estimating a risk absolutely the result will be given in a unit like {events per year} or {cases per 1,000,000 people). If a risk is estimated relatively the risk of one activity is compared with the risk of another activity. In this case it is only possible to compare two activities and to decide which one involves a higher risk lo an individual or a group. The value of the risk estimate cannot be interpreted as an actual frequency but only in comparison to The "Standard" risk. Risk comparisons are only possible if:

- The same incident characteristic is regarded;
- The same adverse effect (damage) is considered;
- The probability distribution of the results is the same;
- the procedure of risk estimation and the applied methods are comparable;
    - the data used are of the same quality with respect to completeness and precision.

3 The conceptual frame of Risk Assessment

3.1 Risk Assessment (RA) is a "scientific" approach to identify, quantify and assess risks in a structured and systematic way to Support the political decision finding process concerning the admissibility and social acceptability of hazards related to naturally occurring events or human activities. The word Scientific is put into quotation marks because R A uses scientific methods but cannot itself be considered as a scientific discipline (see chapter 5).

3.2 Risk Assessment is exclusively orientated towards mankind and their values. This orientation is more or less direct. The endpoint of RA is either the protection of the health of individuals or the population, the avoidance of financial damage to the society or preservation of a "healthy" environment. Thus RA is based on the definition of a "qualified state" and an assessment of deviations from this state. I.e. with respect (o die recent state a quality (e.g. the health Status of an individual or The population, the economic Situation, etc.) or some kind of "Optimum" state with respect to a quality (e.g. no heart attacks at all) can be identified (or defined) and any deviation from this state can be assessed as to whether this deviation is beneficial or not. This approach requires the existence of a frame of values.

3.3 Naturally occurring events as well as human activities demonstrate in principle a quality, which could be assigned to three categories or values - adverse, beneficial or neutral. The classification of an event or activity as adverse, beneficial or neutral constitutes a social judgment on values based on an existing System of values, i.e. the assignment depends on both the society and their values and objectives. In most cases the event or activity is not only related to a characteristic quality, but further to two explicit values (adverse and beneficial).

3.4 In other words events and activities result in a change of the prevailing state of the environment, the society or their values or in an impact on the environment, human or things. If these changes are related to some kind of damage by individual or collective (social) value judgments, the underlying event or activity is classified as Threatening or hazardous and a risk is assigned to the category of such events or activities.

3.5 A different approach to classifying the consequences of events or activities is based on their impact on human urges with the priority of the urges used as an ordering scheme. Urges of lower priority will become dominant if all urges of higher priority are satisfied. E.g., conceding conditions to guarantee that an individual or the society will survive, adverse impacts like premature death, illness, invalidity and genetic damage have a higher priority than the contamination of remote regions by harmful substances.

3.6 The consequences of an event or activity can be classified into classes of pairs of terms with opposing characterizes (beneficial - adverse):

- temporary - permanent
- reversible - irreversible
- single - cumulative
- non synergistic - synergistic
- local - global
- well understand - assumed
- limited - unlimited
- acceptable - unacceptable
- tolerable - disastrous, etc.

In general, events show two features - cause and dimension. With respect to the cause of an event one can differentiate between by natural ("act of God") and human (caused by human activities). Consequences of human acts can be described as wanted consciously, caused by Chance or incidental, i.e. occurring indirectly in the course of an activity aimed at a different purpose.

3.8 Among all possible causes leading to a particular event fundamental causes (or initiating events) can be distinguished. These can in principle be identified by systematic investigation of all causes and the (temporal) development of the event under consideration by using suitable methods (event tree analysis, fault tree analysis, decision tree analysis, path analysis) as well as appropriate models (e.g. the cause, the course and development of the process, human and social behavior, the impact of harmful substances on humans, etc.).

3.9 The dimension of an event is characterized by three coordinates:

- the spatial parameter, describing the area affected by the event;
- The temporal parameter describing the duration of the impact of the event;
- The magnitude parameter describing what is affected as well as the kind and intensity of the impact, e.g. described by chemical or physical quantities.

3.10 The dimension of naturally occurring events and of environmental and health hazards caused by human activities and enterprises varies continuously between ubiquitous (extensive scale, diffuse impact, long duration of the impacts, graduate start) and intensive (most often limited spatial scale, intensive impact, most often short duration of the primary impact, sudden appearance). This classification will also be used to compare different kinds of hazards.

3.11 The hazards considered by RA are of different natures. On one side there are hazards that cannot be influenced or altered by humans (naturally occurring events or "acts of God"), i.e. the probability of their occurrence and their intensity are independent of human activities; only their consequences in terms of damage can be altered by the provision of protection measures. An example of these kinds of hazard is natural disasters, as e.g. earthquakes, floods, hurricanes or volcanic eruptions. On the other side there are hazards whose probability of occurrence and intensity can in principle be influenced or altered by humans. These are hazards resulting from human activities and enterprises. An example is the construction of nuclear power plants. Here not only the consequences, in the case of an accident are dependent on the provisions taken but also the probability that an accident occurs, and the magnitude of the released radioactive inventory, is in the range of human responsibility.

3.12 The methodology of Risk Assessment, used to investigate the kind and scale of a hazard, consists of three tasks:

- Identification or realization of a hazard - Where does the Threat come from?

Identification (or realization) of hazards is related to the perception of what constitutes a hazard, e.g. by consideration of a particular activity, facility or project or by the analysis a complex environment or situation. Formalized schemes are available for this task (hazard identification procedures) but, nevertheless, there is no guarantee that these Schemes will definitely identify all possible hazards.

- Estimation of The risk or quantification of the hazard - How often does a particular event occur and what are the magnitude (or intensity) of the consequences if the event really occurs?

Risk estimation (or qualification of hazards) is concerned with the evaluation of the probability of occurrence of an event and/or with its consequences by quantitative estimation of probabilities, non-qualitative and/or non probabilistic (i.e. deterministic) estimates, expert judgments and estimates, etc.

- Assessment of the results of risk estimation or social evaluation, i.e. assessment of the magnitude of the hazard concerning its importance with respect to the society - How relevant is the estimated risk for the society?

Social evaluation of identified and estimated risks is concerned with the assessment of risks by the society (or better, the responsible government). The result of the evaluation procedure can be:

- Avoidance of the risk (risk aversion), i.e. to refrain from the intended activity;
- Balancing of the expected benefits and damages with subsequent adjustment of the risk to an acceptable level.

Sometimes an additional element of RA is identified, comparing the theoretical predictions with the actual consequences carries out i.e. the follow-up of the results of Risk Assessment during or after the considered activity.

3.16 In fig. 3.1 the three elements of RA are shown as well as their relationship to each other. As indicated in fig. 3.1 none of the three elements of RA is completely independent of the other two elements. E.g. the accurate estimation of the risk of an activity or event implies that all possible (detrimental and beneficial) consequences of the activity or event under consideration have been identified during the preceding Step of hazard identification. On the other band, in reality it will never be possible to estimate a risk in a completely objective way; to some extend subjective estimates influenced by value judgments concerning the degree of importance of parameters, and used to describe the consequences of an activity or event, will always contribute to the result of risk estimation. For this reason, the System of values of the Society will not only be important in the step of social evaluation of a risk but will also influence the results of risk estimation.

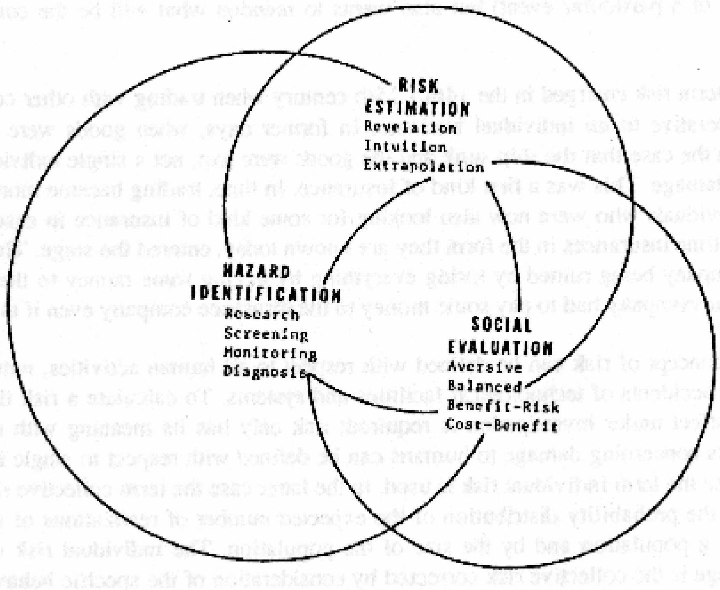

Fig. 3.1: The three elements of Risk Assessment.

3.17 In fig. 3.2 the main objects involved and considered by the Risk Assessment methodology are shown together with their most important attributes. Concerning the object of events these attributes are cause and dimension (see paragraphs 3.7 - 3.9). Consequences are differentiated into gains (beneficial Consequences) and losses (adverse Consequences). With respect to coping actions adoption and adjustment can be identified, if risk avoidance is not possible or aimed at. Adaption means to change the risk not by modifying the source of the risk but e.g. the behavior of people or the utilization of an area. Adaption can be considered as a long-term reaction by individuals or societies with respect to hazards, which in some way is nested and rooted, in human biology, culture and tradition. Adjustment, in contrast, relates to short-term reactions to hazards, carried out consciously or by Chance. Adjustment can be divided into four categories corresponding to its main occurring types: acceptance of the Consequences; division and distributor of the Consequences; measures aimed to modify the hazardous event or its consequences or to reduce the vulnerability of the society with respect to damages; in rare occasions fundamental social changes are made, i.e. changing the place of having, the way of living or the System of production. The object "society" has four attributes: population, e.g. its health Status; social activities; wealth of The society; and the System of values and every single value. With respect to the object "environment" three attributes can be identified: nature or the natural environment; the technological environment; and The social environment, i.e. the society.

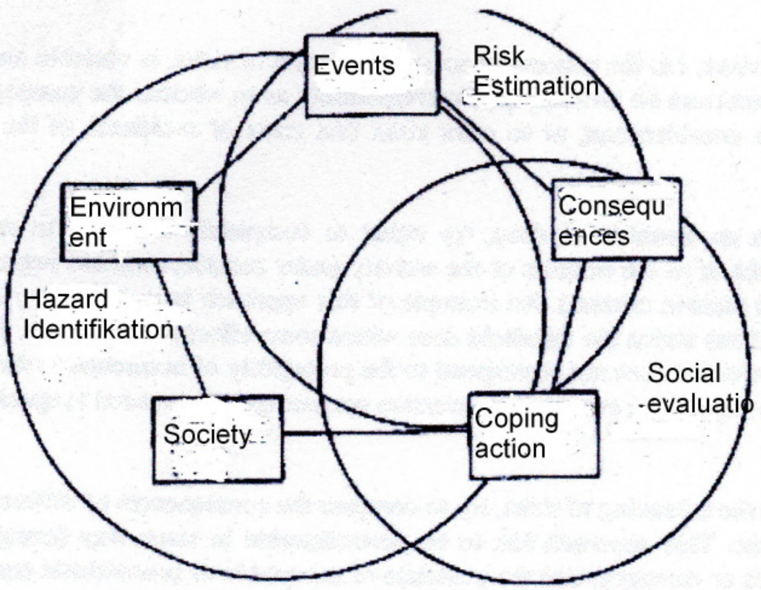

Fig. 3.2: Risk Assessment in coping with environmental hazards.

3.18 Identification of hazards constitutes an aspect of Risk Assessment, which is often not considered in the same detail as e.g. the aspect of risk estimation. However, with respect to hazard identification a consistent basic theory and methodology as well as generic principles are missing. Another problem is the large number of different factors and parameters that are needed to be considered in relation to hazard identification. The perception of hazards is guided by experience and the application of scientific methods using tools as e.g. diagnosis, monitoring, research and screening:

« diagnosis can be defined as the assessment of hazardous events or the consequences of activities, facilities, phenomena, processes or products with respect to possible causes;

• Monitoring can be defined as the recurrent process of observation, recording and analysis of activities, facilities, phenomena, processes or products with respect to hazardous events and consequences.

• research can be considered as not primarily a purpose oriented approach to Risk Assessment, based on excising suspicions concerning assumed or possible threats; in this field applied and critical science are opposed to each other, with the first one dealing with the institutional task of hazard identification by diagnosis, monitoring and screening;

• screening can be defined as the process of hazard identification by using standardized procedures to classify activities, facilities, phenomena, processes and products with respect to their hazard potential.

All the aforementioned methods are concerned with a relative suspicion about an assumed or possible hazard. Fig. 3.3 shows the sequence of elements of hazard identification.

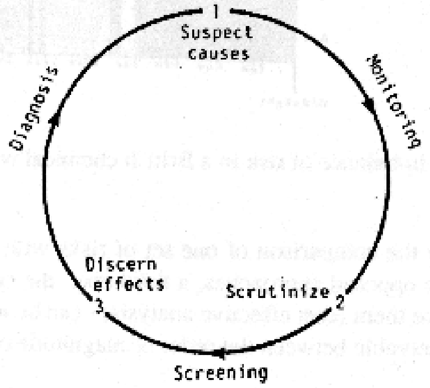

Fig. 3.3: Sequence of hazard identification elements.

3.19 The theory and methodology of hazard identification, on the one hand is guided by scientific based knowledge, conclusions and search algorithms and on the other hand related to statistical conclusions with respect to the categorization of potential sources of hazards and their assignment to different risk qualities (e.g. safe, unsafe, risky, necessity of further investigations, etc.). Based on the fact that unambiguous mechanisms and generic principles of hazard prediction are not existent (i.e. there is no possibility to predict hazards without using the experience and knowledge concerning equal or similar hazards and their consequences and effects) it is absolutely necessary to fall back on methods which are either unreliable (serious hazards will not be identified), very expensive (data, barely needed, or of low benefit will be gathered, costing a lot of money), or tendentious (consistently misleading).

3.20 Risk estimation is guided by three methods: extrapolation, Intuition, and revelation:

- extrapolation is related to the assessment of risks based on individual or collective experiences; it can be differerentiated between prospective oriented extrapolation, retrospective oriented extrapolation, and horizontal extrapolation:
    - prospective oriented extrapolation is related to the estimation of the probability of occurrence of future events based on historical experiences (future events are considered simply as repetition of events in the past); frequently, probability theory, probability distributions, and models describing the occurrence of particular events will be used (law of large numbers) as well as the prediction of the occurrence of future events based on the non occurrence of these events in the past;
    - retrospective oriented extrapolation is related to the estimation of unknown, but conceivable events or consequences based on already known events and consequences having no direct experiences available; by reducing a hazardous event to a sequence of initiating and contributing events, for which experiences are available, the overall event will be extrapolated (this approach is very similar to the methodology of fault tree analysis of complex technological Systems whose overall structure will also be reduced to its components and subsequently analyzed; with respect to these components either the failure rates are well known or the failure rates can be estimated by using existing physical laws);
    - horizontal extrapolation is related to the transfer of experiences by using analogies to a different, but similar condition, place or Situation or by combining Information;
    - all methods of extrapolation are based on the theory of statistical reasoning with an underlying statistical theory, either the frequency theory or the theory of Bayes (degree-of-belief);
- Intuition is related to the individual judgment on the probability of occurrence of an event and/or its consequences based on a subjective, inner System of values; conclusions are drawn using less explicit information compared to other ("usual") situations of decision-making;

• revelation is related to the estimation of the probability of occurrence of events and/or their consequences by prophecy or supernatural forces.

3.21 Frequency, the result of a risk estimation will not be an exact number, but only the order of magnitude of the risk under consideration will be given, i.e. only the range of a risk will be quantified or the Position of a risk on a relative scale. Using this approach it will be possible to compare the result of Die risk assessment of an activity, event, facility or System with those of other activities, events, facilities or Systems as well as with risk estimations based on the specification of fractiles given expert judgments. Furthermore, scenarios can be used to explain problems and decisions in a clearer way. By introducing a number of different scenarios complex combinations of events and their consequences, both in the future and in the past, can be investigated and the Imagination stimulating concerning the assessment of risks with very low probability of occurrence.

3.22 Risk estimations involve a large number of different "Software" problems, e.g.:

• the definition and translation of problems into the language used by scientific theories and models, e.g. probability theoretical expressions and their translations into common language, independence, etc.;

• psychological problems (e.g. transfer of experiences into opinions, intuitions, heuristics, etc.)

• limitation of the process of consciousness (e.g. dissonances of the conscious, prejudices, etc.)

3.23 The assessment of risks, i.e. the process of social evaluation of risks, is variable and relative and the methods of risk assessment can be differentiated corresponding as to whether the comparisons carried out relate to the risk under consideration, or to other risks (the costs of avoidance of the risk or to its benefits).

3.24 Methods, based on an aversion to risks, try either to completely avoid or to minimize risks. Comparision with other risks or of the benefits of the activity under consideration are neglected (absolute criteria and taboo, but also relative criteria). An example of this approach is to reject any dose (e.g. of a substance or ionising radiation) above the threshold dose where some effect is observable. Frequency, The ordering of the risks to be avoided does not correspond to the probability of occurrence or the magnitude of the consequences of the corresponding events. Risk aversion sometimes is not related to specific risks but to risk generally.

3.25 Methods, based on the balancing of risks, try to compare the consequences of different activities or events and to equalize these. This approach has to be generalizeable in some way (Comparison of the frequency of death, diseases or damages) and the existence of acceptable or unavoidable consequences are required, i.e. the level of acceptance with respect to risks is larger man zero. Some authors identify "natural" limits of the acceptable risk (the upper limit is defined by the average annual per capita risk of illness of about IO^{-2} and the lower limit is defined by the average annual per capita risk from natural events of about IO^{-6}). Balancing of risks in the case of an uneven exposition to risk of individuals of a given population, of different societies, in different periods of life or during a single day is very complicated. Fig. 3.4 shows the unbalanced exposition to risk during one day of a British worker in the chemical industry; in a single normal working day the risk varied by a factor of about 600.

3.26 Considering the comparison of one set of risks with other risks and the Comparison of risks with their benefits as two opposed approaches, a third one, the comparison of risks with activities and the cost to eliminate or reduce them (cost effective analysis) - can be identified, lying between these two ends. There is a relationship observable between the order of magnitude of a risk and the efforts to reduce the risk:

risks of fatal accidents with a probability of the order of magnitude of IO^{-3} per persons a year are unusual; if a risk approaches this order of magnitude immediate Steps to reduce the hazards are carried out, because this risk level will be considered as unacceptable by all people;

- if accidents occur with a frequency of the order of magnitude of $I\,O^{-4}$ per person a year people are willing to spend money, in particular public money, to control for the causes of the risk, e.g. traffic lights, police or fire brigades; at this order of magnitude safety Slogans for accidents show an element of fear ("The life you save may be your own");
- risks of fatal accidents at the Order of magnitude of IO^{-5} per person a year are still considered unacceptable by society and some persons will accept some degree of inconvenience to reduce the risk, .e.g. they do not travel by airplane; safety Slogans

for these risks have a precautionary ring ("Never swim alone", "Never point a gun at another person", "Keep medicines out of the children's reach");

- risks of fatal accidents at the order of magnitude of 10^{-6} per person a year are not of great concern to the average person; possibly being aware of them, the average person feels that they will never happen to her or limit; phrases associated with this frequency of occurrence of risks have an element of resignation ("Lightning never strikes The same place twice", "An act of God").

3.27 Risk benefit analyses are based on the consideration of the costs and benefits of risks and their comparison. Risk is here defined as a Surrogate of the overall social costs (e.g. the adverse consequences of risk is measured in units of expected fatalities per hour of exposure and the benefits are measured in monetary units, e.g. US $). The distribution of risks, i.e. adverse consequences and benefits must not always be the same, i.e. relate to the same person, the same place or time or the same social class. A theorem, defined by Starr, which is not generally accepted, assumed that the voluntary and non-voluntary acceptable risk increased with the third power of the benefit. From this theorem Starr derived the following implications with respect to social politics:

- the frequency of fatal diseases constitutes with respect to the definition of (he acceptability of risks an upper limit: about 1 in 100 years;
- naturally occurring disasters ("act of God") tend to see a base guide for risk - somewhat more than 1 in a million years - similar to the 'intrinsic' noise level of physical Systems; man-made risks at this level can be considered almost negligible, and can certainly be neglected if they are several Orders of magnitude less;
- social acceptance of risk increases with the benefits to be derived from an activity; the relationship appears to be non-linear, with Starr's study suggesting that the acceptable level of risk is an exponential function of the benefits (real and imaginary);
- the public appears willing to accept voluntary exposure to risks roughly 1,000 times greater than involuntary exposure.

4. Risk Assessment methodologies

4.1 Deterministic and Probabilistic Safety Assessment

There exists no single methodology of Risk Assessment. However, depending on the nature of the problem under consideration, an adequate methodology must be chosen. Nevertheless, some criteria exist which should be taken into account if a Risk Assessment is conducted, e.g.:

- the overall problem has to be identified and described in clear words;
- the whole problem has to be divided into simple problems, which could be investigated more easily than the overall problem;
- a diagram showing the relationship between the single problems should be drawn lo identify correlations and dependencies of different problems;
- with respect to each problem the tasks, which have to be solved, and the questions, which have to be answered, should be stated in clear words;
- all data and information needed to solve the problems should be gathered, together with their corresponding reliabilities and uncertainties;
- the identified tasks should be solved, if possible, by using different methods or methodologies to verify the gained results;
- the reliability of the gained results should be investigated and their uncertainties given together with the results;
- a written documentation should be prepared concerning the overall approach selected, as well as the data and information used, the calculations carried out, possible estimations or judgements made, etc.; this documentation should be clear, complete and understandable, beginning with a clear definition of the problem and the selected approach, written in a generally understandable language.

4.2 Risk Assessment is concerned with a number of different hazards, e.g.:

- hazards related to "normal" (i.e. without accidents), Operation of facilities, producing or handling harmful substances;
- hazards due to accidents in the aforementioned facilities;

- hazards related to the use of drugs of other Chemical substances, which become harmful if a threshold dose is exceeded;
- hazards due to the use of Chemicals at the working place or in the household (paintings, pesticides, fungicides, etc.);
- hazards at the working place in general (e.g. accidents, diseases, injuries);
- hazards related to certain activities (e.g. car driving, diving, motorcycling, mountain climbing, etc.);
- hazards related to naturally occurring events (e.g. earth quakes, floods, hurricanes, etc.).

The most important endpoints of Risk Assessment, i.e. risk categories, are death, diseases (especially cancer), injuries and financial losses.

4.3 In the following some of the fields of Risk Assessment will be considered more closely, i.e. risks posed by naturally occurring events and by human activities, especially technological and environmental risks. At the beginning a fundamental difference in Safety Assessment methodologies will be considered.

4.1 Deterministic and Probabilistic Safety Assessment

4.1.1 Safety and Risk Assessment are closely related methodologies. The task of Safety Assessment is to prove whether or not a technological facility or System meets specific requirements concerning the safety design. The defined requirements are supposed to guarantee that failures or accidents during Operation of the facility or System do not occur. Thus, fulfilling the defined safety requirements the facility or System will withstand some failures or accidents (so called design basis accidents). Risk Assessment is now used to investigate the probability that beyond design basis accidents will occur, i.e. accidents for which the System and its safety equipment are not designed. This can be due to either that actual safety relevant System

Parameters lie outside the range considered by the design or that accident sequences occur during Operation, which were not taken into account by designing the System.

4.1.2 The deterministic estimation of risks is based on the application of well known deterministic, i.e. non-probabilistic, laws to analyse and describe the process under investigations. For example, to determine the maximal pressure a pressure vessel would withstand without failure for some time, two approaches are possible:

4.1.3 Concerning the deterministic approach of Safety Assessment, at the beginning a threshold will be defined (deterministic), beyond which extreme conditions will not be considered with respect to the safety requirements the System has to fulfil since the occurrence of these extreme conditions is not expected. In the end, an implicit and qualitative estimation of the probability that the threshold will be exceeded is hidden behind the deterministic approach. Deterministic Safety Assessment is often considered as conservative, i.e. assumptions will be used which are more cautious than they probably need to be in reality. Thus, this approach tries to lie on "the safe side" in assessing the safety of a System.

4.1.4 concerning the probabilistic approach of Safety Assessment, probabilities will be explicitly used to quantify uncertainties. These uncertainties can be of different kinds: i.e. related to System parameters, the state of The system, the model used to describe the System, the completeness of the description of the System, the physical laws and constant used with physical equations, or related to the nature of the overall process considered. One of the problems of Probabilistic Safely Assessment is to combine different probability distributions as the whole System will be divided into its components, all of them having different distributions with respect to their failure probability. In some cases the use of Probabilistic Safety Assessment has some advantages compared to the deterministic approach, especially if the knowledge concerning the System or the underlying processes are restricted or if the latter are of a stochastic nature. Probabilistic Safety Assessment is considered as investigating the best estimate of hazards, i.e. based on real and not on conservative assumptions. Thus, the result is interpreted as a real risk and not as a maximum estimation of the risk.

4.1.5 In the sense of these definitions the qualifiers "deterministic" and "probabilistic" can be transferred to the methodology of Risk Assessment.

4.2 Risk Assessment of natural hazards

4.2.1 So-called natural hazards have always been a part of human history (see table 4.2.1 and 4.2.2). But in the modern world, there is an increasing paradox between the outstanding achievements in science and medicine, which make life safer and healthier, and the continuing death and destruction associated with the extremes of nature. The paradox is complicated by the fact that science itself is not without hazard and has led to the comparatively recent emergence of 'man-made' threats, which arise, from the misapplication, misuse and failure of technology. People are now at risk not only from geophysical events, such as earthquakes and floods, but also from industrial explosions, releases of toxic substances and major transport accidents. A growing awareness of hazard is further encouraged because all disasters make news. The visible results of hazards, both natural and man-made, feature repeatedly on television screens throughout the world and seem to make ever more frequent headlines.

Event Type	Time Period	Maximum No. of Deaths per Event	Average No. of Deaths per Event	Frequency (events/year)
Air crashes	1965-1969	155	78	6.00
Earthquakes	1920-1970	180,000	25,000	0.50
Explosions	1950-1968	100	26	2.00
Major fires	1960-1968	322	35	0.67
Floods (tidal waves)	1887-1969	900,000	28,000	0.54
Hurricans	1888-1969	11,000	1,105	0.41
Major rail crashes	1950-1966	79	30	1.00
Major marine accidents	1965-1969	300	61	6.00

Table 4.2.1: Major disasters that hit the headlines in the USA.

Event Type	Number	Percentage
Floods	343	32
Hurricans	211	20
Earthquakes	161	15
Tornadoes	127	12
Snowstorms	40	4
Thunderstorms	36	3
Landslides	29	3
Rainstorms	29	3
Heatwaves	22	2
Volcanoes	18	2
Coldwaves	17	2
Avalanches	12	1
Tsunanüs	10	1
Fog	3	
Frost	2	-
Sand and dust storms	2	-

Total	1,062	100

Table 4.2.2: Global disasters by type 1947-81.

4.2.2 One main characteristic of natural hazards is that they are not evenly distributed, i.e. there are some regions in the world which are much more often affected by natural disasters than other regions. Earthquakes, e.g., are much more common in Japan than in the U.K. This uneven distribution results first of all in an uneven distribution of hazards among the population of the world (see table 4.2.3). Furthermore, because the possibility of taking preventive and protective measures against natural hazards are very different for single countries, depending on their respective economic power, not only the frequency of natural disasters will be distributed unevenly, but also the consequences of these disasters as expressed in the number of death or injuries (see table 4.2.4 and 4.2.5). On the other hand, the economical damage in the case of a natural disaster will in general be much higher in high industrialized countries than in under developed countries. In table 4.2.6 the number of natural disasters, as well as the average disaster related deaths and damage per event, ranked separately by country, for the period 1900-88 is shown. As can be seen the rankings with respect to the number of deaths per event (countries with low income per capita at the top) and with respect to the economic damage (in US $) per event (countries with high income per capita at the top) are opposed to each other.

Continental Area	Disaster Incidence (%)	Lives Loss (%)
North America	33	1.0
Carribean and Central America	7	4.5
South America	6	4.2
Europe	11	2.2
Africa	3	2.0
Asia	38	85.7
Australia and Oceania	2	0.4
Total	100	100

Table 4.2.3: Incidence of natural disasters and loss of

life by continental areas, 1947-81.

Country	Deaths/Million Population
High-risk group	
Bangladesh	3,958
Guatemala	3,174
Nicaragua	2,590
Honduras	1,995
Iran	1,539
Peru	1,309
New Guinea	1,283
Haiti	1,189
South Korea	1,021
High-income group	
Japan	276
United Kingdom	89
USA	51
France	19
Canada	12
Australia	11
West Germany	10
Switzerland	9
South Africa	1

Table 4.2.4: Ranked list of countries with more than I ,000 disaster related deaths per million Population with comparative disaster related deaths for selected high-income countries 1947-81

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Country and Economic Status	Cyclone Events	Deaths	Deaths per Event
Japan - high	11	254	23

income			
Philippines - middle income	22	4,322	196
Bangladesh - low income	8	10,733	1,341

Table 4.2.5: Incidence of tropical cyclones and number of people killed in selected high-, middle and low-income countries 1980-8.

No. of Disasters		No. of Disaster Related Deaths		Disaster Damage(10^3 US $)	
India	199	USSR	284,334	Italy	611,694
Phillipines	134	PR China	80,812	Spain	374,686
Indonesia	110	India	44,379	Chile	121,505
Bangladesh	109	Bangladesh	26,981	USSR	90,645
Japan	91	Ethopia	16,138	Argentina	84,758
PR China	89	Niger	7,826	Mexico	80,563
Brazil	68	Mozambique	7,262	Colombia	51,969
Mexico	60	Italy	2,949	Pakistan	39,370
Peru	55	Pakistan	2,061	China	39,296
Iran	53	Japan	2,005	Peru	32,498
Turkey	43	Peru	1,355	India	31,940
Colombia	39	Chile	1,107	Sri Lanka	31,734
Italy	39	Iran	1,103	Japan	30,416
Korea	38	Turkey	1,027	Bangladesh	26,831
Chile	37	Colombia	705	Korea	25,116
Burma	36	Haiti	429	Plüllipines	13,393
Pakistan	33	Vietnam	412	Haiti	10,460
Vietnam	32	Sri Lanka	317	Turkey	10,320
USSR	31	Mexico	287	Mozambique	9,588
Ecuador	30	Ecuador	261	Ecuador	8,830
Argentina	29	Indonesia	225	Brazil	6,964

Sri Lanka	29	Phillipines	222	Indonesia	6,838
Niger	27	Argenüna	202	Niger	4,322
Haiti	26	Burma	176	Burma	4,280
Ethiopia	25	Korea	107	Ethopia	3,129
Mozambique	25	Spain	106	Vietnam	2,296
South Africa	25	Brazil	99	Iran	1,415
Spain	25	South Africa	73	South Africa	40

Table 4.2.6: Number of disasters, average disaster related deaths and damages per event, ranked separately by country (with number of disasters > 25) 1900-88.

4.2.3 Thus, the individual risk, e.g. of death, is unevenly distributed in space (see table 4.2.2), in time (see table 4.2.3 and flg. 3,4) and with respect to the cause (see table 4.2.4). This fact has to be taken into account if the individual or collective risk related to some natural or man-made hazard is considered. Besides the involuntary risks, listed in table 4.2.4, depending on individual activities and behaviour, a number of voluntary risks exist which in some cases could represent a significant contribution to the overall (individual) risk of a person. The theoretical relationships between the severity of environmental hazard, probability and risk is shown in fig. 4.2.1. Hazards to human life are rated more highly than damage to economic goods or the environment.

Age Group	**Individual Risk per Year (x 10^{-3})**
0-4	3.3
5-9	0.3
10-14	0.3
15-19	0.6

20-24	0.7
25-34	0.8
35-44	1.8
45-54	5.8
55-64	14.8
65-74	36.7
75-84	87.7
>85	205.2

Table 4.2.3: Individual risk of death (all causes) according to age for the U.K.

Involuntary Risk	Risk of Death / Person / Year
Struck by automobile (USA)	1 in 20,000
Struck by automobile (UK)	1 in 16,600
Floods (USA)	1 in 455,000
Earthquake (California)	1 in 588,000
Tornadoes (Midwest)	1 in 455,00
Lightning (UK)	1 in 10 million
Falling aircraft (USA)	1 in 10 million
Falling aircraft (UK)	1 in 50 million
Pressure vessel explosion (USA)	1 in 20 million
Release from atomic power station	
at side boundary (USA)	4 in 10 million
at 1 km distance (UK)	1 in 10 million
Flooding of dike (Netherlands)	1 in 10 million
Bites of venomous creatures (UK)	1 in 5 million
Leukaemia	1 in 12,500
Influenza	1 in 5,000
Meteorite	1 in 100 billion

Table 4.2.4: Risk of death from involuntary risk.

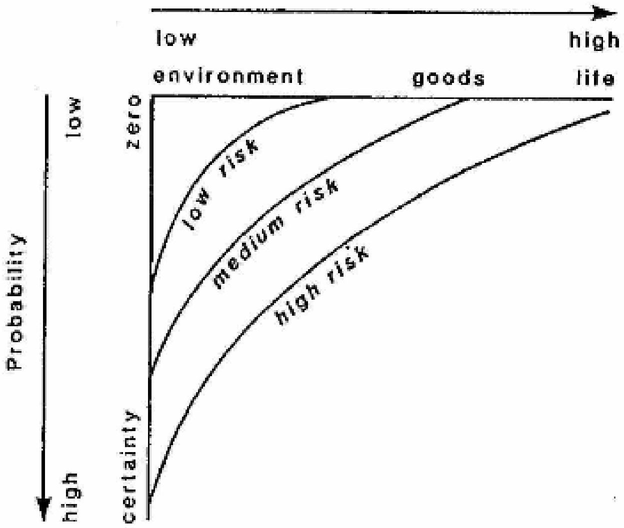


Fig. 4.2.1: Theoretical relationships between the severity of environmental hazard, probability

4.2.4 Besides external factors, e.g. the representation and visualisation of disasters on television and in the newspapers, the perception of natural hazards depends on internal factors, e.g. the sensitivity to hazards in general as well as the socio-economic tolerance and the attitude towards a natural resource. This is demonstrated in fig. 4.2.2. A geophysical element is considered as a resource if its intensity or magnitude is within a band of tolerance. Above or below a damage threshold, the physical element is perceived as a hazard. Human sensitivity to natural hazards represents a combination of physical exposure, reflecting the range of natural (and technological) events and their statistical variability at a particular location, and human vulnerability, reflecting the breadth of social and economic tolerance available at the same site. This is shown in fig. 4.2.3. In case A the band of social and economic tolerance remains constant as well as the statistical variability of the natural event but its average value decreases through time. Case B represents a constant band of tolerance and constant mean value but an increased variability. Finally, in case C the physical variable does not change but the social band of tolerance narrows. In all cases a physical element, considered at the beginning as a resource, becomes a hazard.

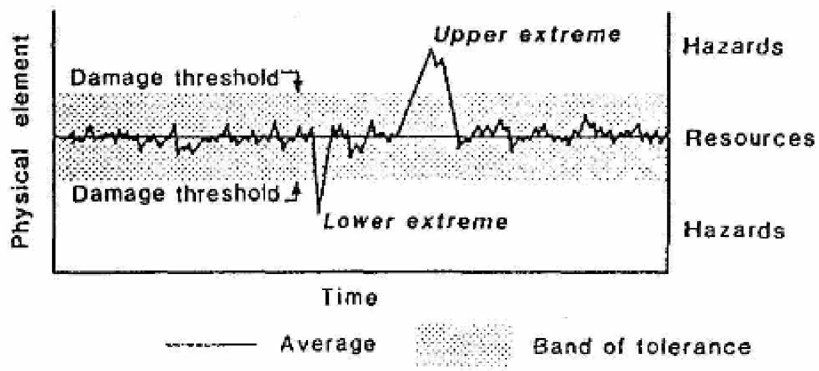


Fig. 4.2.2: Sensitivity to environmental hazards expressed as a function of the variability of geophysical elements and the degree of socio-economic tolerance. Within the band of tolerance, events are perceived as resources; beyond the damage thresholds they are perceived as hazards.

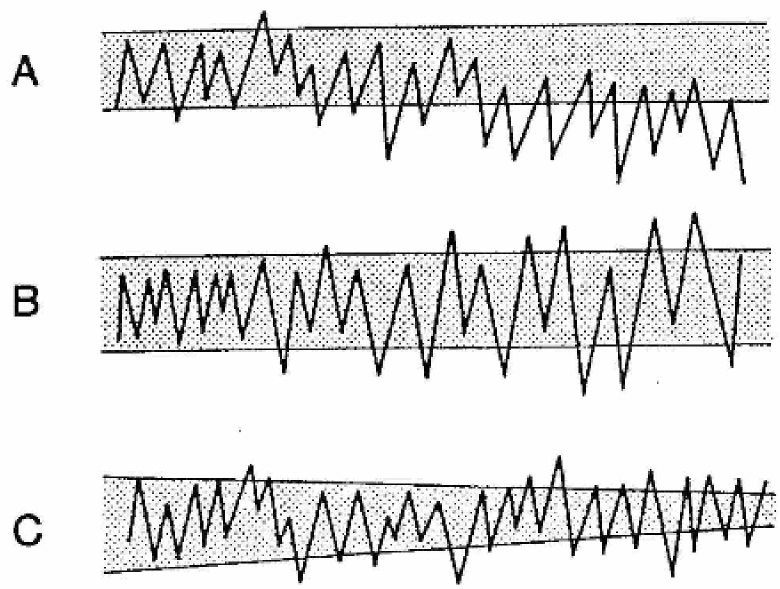


Fig. 4.2.3: A schematic illustration of changes in human sensitivity to natural hazard due to variations in physical events and socio-economic tolerance. In each case the risk perception of disaster increases through time.

4.2.5 The impact of natural disasters are intense compared, e.g., to technological or voluntary is accepted risks of a civilization. Fig. 4.2.4 shows a spectrum of natural and man-made hazards as well as their impact, ranked from intense, i.e. of short duration with direct consequences, but not necessarily very limited in space, to diffuse, i.e. with indirect consequences (late effects), not directly attributable to a particular activity or impact. In fig. 4.2.5 the potential impact of natural hazards in terms of losses and gains, both direct and indirect, is depicted. Some of the effects can be considered as tangible with other effects as intangible. Direct losses and gains relate to damages (deaths, injuries, destruction) and benefits (financial aid for reconstruction, food, medicine, etc.) to the population and the region affected by the disaster. Indirect losses arise mainly through the second-order consequences of a disaster, such as the disruption of economic and social activities in a Community or the onset of ill health amongst disaster victims. Indirect gains are even less well understood. They represent the very long-term benefits enjoyed by a Community as a result of its hazard-prone location. In fig. 4.2.6 the disaster impact pyramid showing the outward spread of awareness of the event from the possibly relatively small number of victims in the direct hazard zone to the global population via donation of aid and mass media is shown.

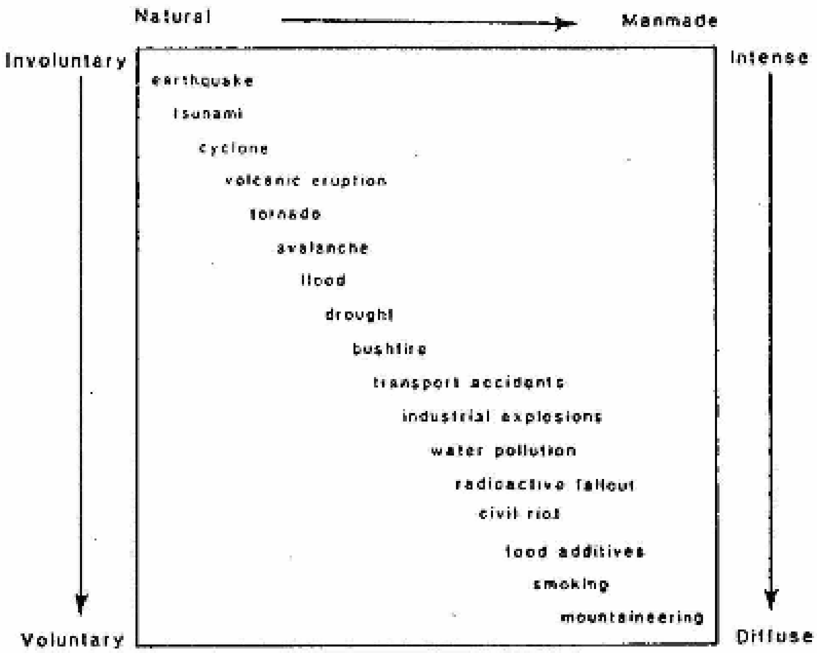


Fig. 4.2.4: A spectrum of natural hazards from geophysical events to human activities. Hazards which are increasingly man-made tend to be more voluntary in terms of acceptance and more diffuse in terms of their impact.

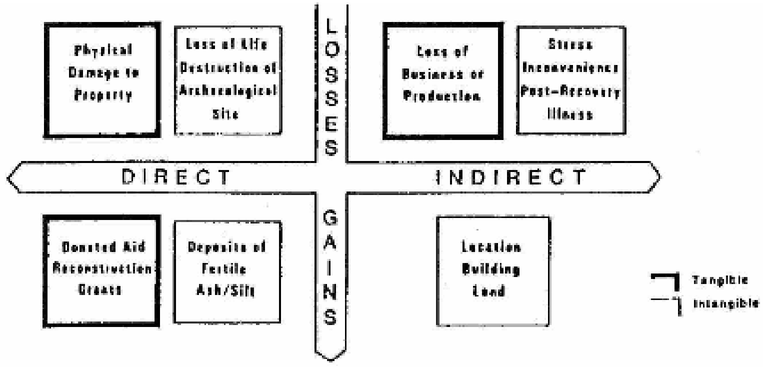


Fig. 4.2.5: The potential impact of natural hazards in terms of losses and gains, both direct and indirect, with an indication of some tangible and intangible effects.

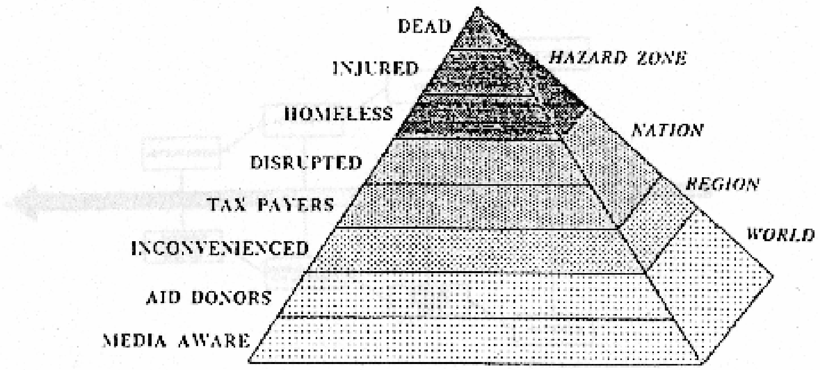


Fig. 4.2.6: The disaster impact pyramid showing the outward spread of awareness of a disaster.

4.2.6 In general, natural hazards exist at the interface between the natural event and the human use System as well as the society with its characteristics of tolerance and vulnerability. In responding to hazards individuals or the society can either modify the natural events or its consequences in the environment or the use of the environment by humans (or both) (see fig. 4.2.7). Comprehensive management of natural hazards, involving both assessment and response, can be seen as to consist of four chronological stages operating as a close loop (although the stages often over-lap) because a major aim of hazard management is to learn from experience by feedback.:

1. *Pre-disaster planning:* This covers a wide range of activities such as the construction or defensive engineering works, land use planning and the formulation, dissemination and maintenance of evacuation plans.

2. *Preparedness:* This stage reflects the degree of alertness immediately before the onset of the hazard; for example, arrangements for emergency warnings to be issued and the effectiveness with which public officials can mobilise an evacuation plan.

3. *Response:* Another broad category dealing with events immediately before and after they have happened, including reaction to warnings and emergency relief activities.

4. *Recovery and reconstruction:* These are much longer-term activities that attempt to return an area to normality after severe devastation. Such devastation can occur after a major event even in those areas apparently well prepared for disasters after a major event.

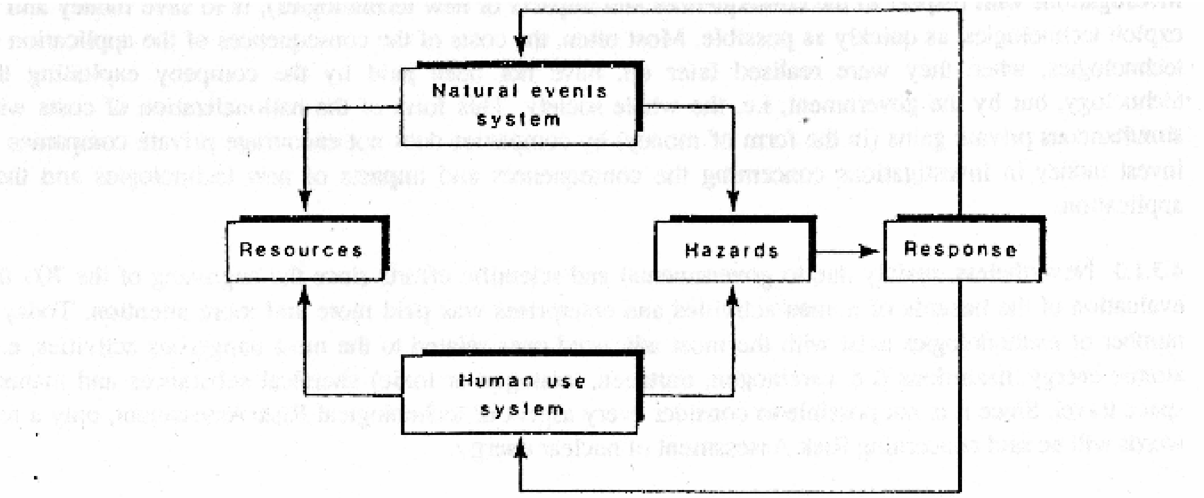


Fig. 4.2.7: **Natural hazards at the interface between natural events and human use system and society.**

4.3 Risk Assessment of hazards caused by human activities

4.3.1 **Risk Assessment of technological hazards**

4.3.1.1 The evaluation of hazards related to human activities and enterprises, both in relation to the environment in general and the health of humans in particular, is a continuously growing field. It becomes more and more important as the possible consequences and impacts of the application of technology, and changes to the environment, are of global dimension. One example is the question as to how fast and to what extent the global temperature will increase in future due to the emission of chemical substances affecting the protective ozone layer of the earth. At the beginning of the production and use of these substances the problem of the chemical reactions of these substances with ozone in the upper atmosphere was not considered at all. Even in the case that these chemical reactions are very rare the enormous amount of the substances produced will constitute a serious problem in producing global warming.

4.3.1.2 The development of adequate methodologies to assess the hazards and risks of human activities and enterprises lags far behind the progress of technological developments. Furthermore, due to economic reasons, the main interest of companies of the western capitalistic System (provided in principle with the necessary scientific Knowledge and technology as well as financial possibilities to carry out more thorough investigations with respect to The consequences and impacts of new technologies), is to save money and to exploit technologies, as quickly as possible. Most often, the costs of the consequences of the application of technologies, when they were realised later on, have not been paid by the Company exploiting the technology, but by the government, i.e. the whole society. This form of the nationalization of costs with simultaneous private gains (in the form of money) by companies does not encourage private companies to invest money in investigations concerning the consequences and impacts of new technologies and their application.

4.3.1.3 Nevertheless, mainly due to governmental and scientific efforts since the beginning of The 70's the evaluation of the hazards of human activities and enterprises was paid more and more attention. Today a number of methodologies exist with the most advanced ones related to the most dangerous activities, e.g. atomic energy, hazardous (i.e. carcinogen, mutagen, teratogen or toxic) chemical substances and manned space travel. Since it is not possible to consider every aspect of technological Risk Assessment, only a few words will be said concerning Risk Assessment of nuclear energy.

4.3.1.4 In the first years (i.e. from 1945 to about 1965) of the design and construction of nuclear power plants for the production of electricity by nuclear fission questions of nuclear safety (criticality considerations, reactor shut-down, etc.), then no hydraulics (cooling conditions, behaviour of steam and vapour, flow conditions, etc.) and material properties (material fatigue, neutron absorption, material faults, thermal resistance, etc.) were analysed. Safely was mainly considered by investigations concerned with selected properties or features. No systematic and overall evaluation of the possible accidents and their consequences, both with respect to the power plant itself and the surrounding of the facility, as well as the capabilities of the safety Systems was carried out (apart from one investigation, carried out in the USA about 1955, considering the consequences, e.g. injuries, diseases and deaths, of an accident in the population living in the vicinity of a nuclear power plant). The methods used were mainly theoretical calculations, material testing, experiments and investigations of the reliability of components and Systems.

4.3.1.5 With the publication of the Rasmussen Report in the USA in 1975 (WASH-1400) the first assessment of accident risks in US commercial nuclear power plants and their consequences to the health of the population and the environment became available. Subsequently other countries having commercial nuclear power plants in Operation also conducted Risk Assessments of their reactors. These first studies (Risk Studies), using probabilistic methods of investigation, mainly focus on one particular nuclear power plant or consider accidental risks and their consequences in general. The main objective of these activities was to estimate the absolute risk (i.e. the probability) of severe reactor accident (melting of the core) with large releases of radioactive materials as well as the consequences to the population. The operational safety was evaluated by reliability analyses to estimate the failure probability theoretically before it was available empirically, i.e. by observation of real failures.

4.3.1.6 Later on the objective of Risk Assessment, now called Probabilistic Safety Analysis (PSA), changed. Nowadays Probabilistic Safety Analyses are carried out, not to estimate the absolute overall risk of severe nuclear accidents, but to evaluate the relative contribution of different accident sequences to the overall risk of a severe nuclear accident with respect to a particular nuclear power plant. Thus PSA is used as an instrument to identify the most vulnerable and less reliable components and Systems having the largest contribution to the total risk. In consequence PSA for different nuclear plants cannot be compared directly with respect to their absolute risk because the data used, as well as the respective component and System availabilities and their overall design, depend on the particular facility. On the other hand, recurrently conducted PSA for the same nuclear power plant can be compared (Living PSA).

4.3.1.7 The analysis of the reliability of a System rests on the methodology of fault tree analyses. The latter is the systematic investigation of the interaction of single components of a System and their representation in a logical structure (fault tree) used to identify that combination of component failures, which will result in a failure of the whole System. In fig. 4.3.1.1 the Symbols commonly used by fault trees are shown. Using the failure probability of the single components (which are in general more easily available than those of the whole System) the failure probability of the System can be extricted. Even if the System is very reliable, and no failures have occurred so far during Operation, the failure probability can in principle be estimated after a relative short time of Operation. Furthermore, human errors, e.g. in testing, maintenance or Operation of a System, can also be incorporated into a fault tree. In figs. 4.3.1.2 and 4.3.1.3 an examples of a fault trees of one relatively simple Systems is shown. It is an example of the failure of a wake-up device and the predicted failure rate is shown.

4.3.1.8 There are three main problems with fault tree analysis. The first one is concerned with the determination of the failure probabilities of the components of a System. In reality, the Operation experience is not often sufficient to determine The failure probabilities of components. In these cases there are in principle three possibilities:

1. to use the experience and data from other facilities of the same type;
2. to use the experiences and data from similar components of similar or the same facility;
3. to use subjectively estimated data.

Especially with respect to human errors üie uncertainty of the "failure" data very often is quite large or no data exist at all. In consequence the activities of operators cannot be estimated reliably.

4.3.1.9 The second problem with fault tree analysis is related to the fact that for real Systems the belonging fault tree is very complex and quite difficulty to construct and to analyse. Thus there is no guarantee that the constructed fault tree considers all details of the System. The last one of the main problems is concerned with so-called "common mode failure". Especially in the case where the System has a high degree of redundancy, i.e. there are a number of Systems, all of them having the same function, the failure of several of the redundant components, caused by a common cause, can affect the overall reliability of the System. For this reason one task of fault tree analysis is to discover interdependencies between several components, which in practice is a very complicated exercise because no systematic procedure exists.

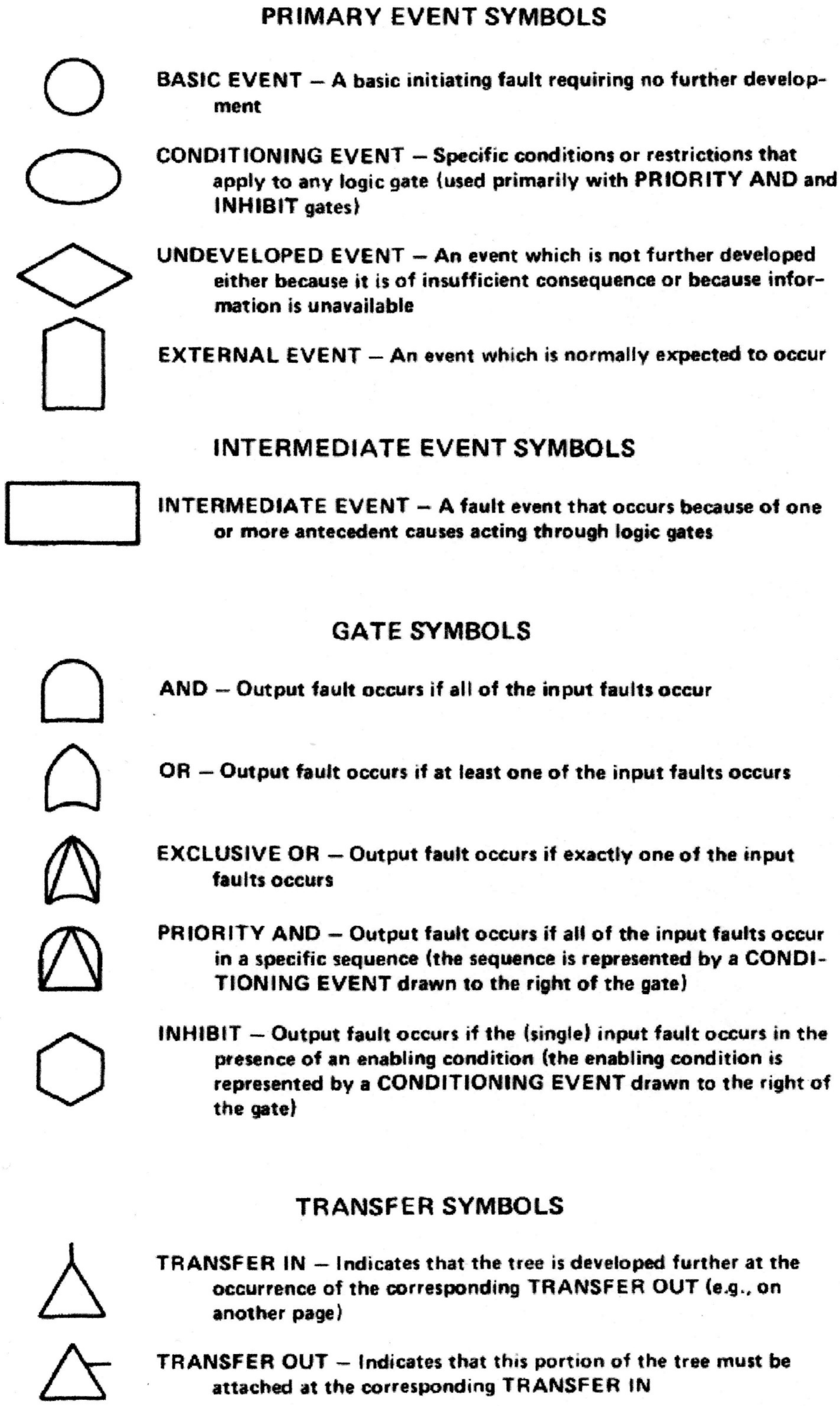


Fig 4.3.1.1 : Fault tree symbols commonly usesd

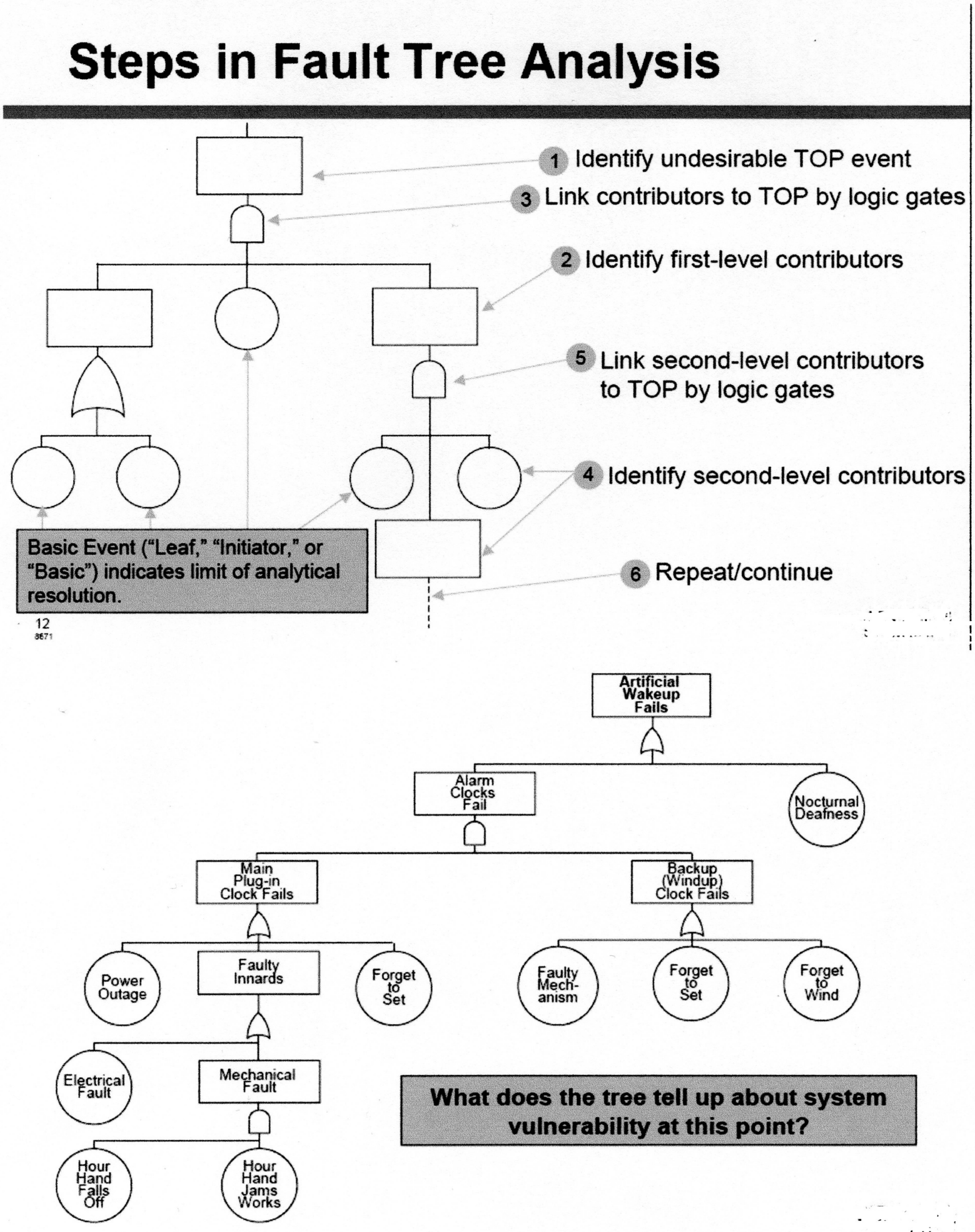


Fig 4.3.1.2 Example 1: Steps in Fault Tree Analysis for the failure of a wake-up device

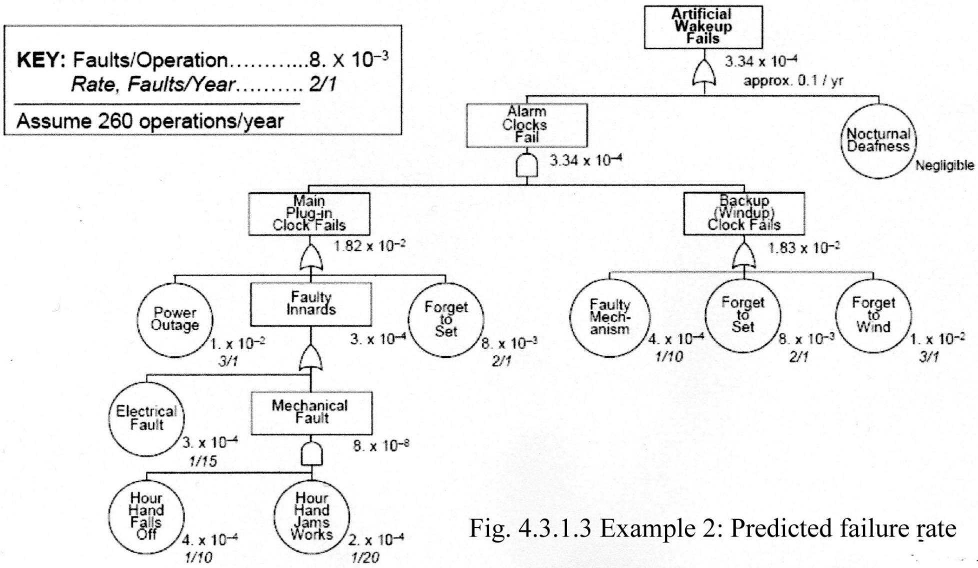


Fig. 4.3.1.3 Example 2: Predicted failure rate

4.3.1.10 Risk Studies try to estimate the risk of nuclear accidents by using analytical tools. For this purpose besides determining the failure probabilities of components and Systems, the consequences of these failures have to be evaluated. This can be achieved by combining fault tree analysis with event tree analysis.

4.3.1.11 Event tree analysis shows, in a structured form, the consequences, i.e. the course of events, of initiating events. The course of events following an initiating event will depend on whether or not the safety and protection Systems, provided to prevent a disturbance resulting in an accident as well as to limit the consequences of any accident, fulfil their tasks. The probability of occurrence of different event sequences is determined by combining the probability of the initiating event(s) and the failure probabilities of safety installations as they are determined by fault tree analyses. Before conducting an event tree analysis the minimum requirements with respect to the availability, capacity and function ability of the safety and protection

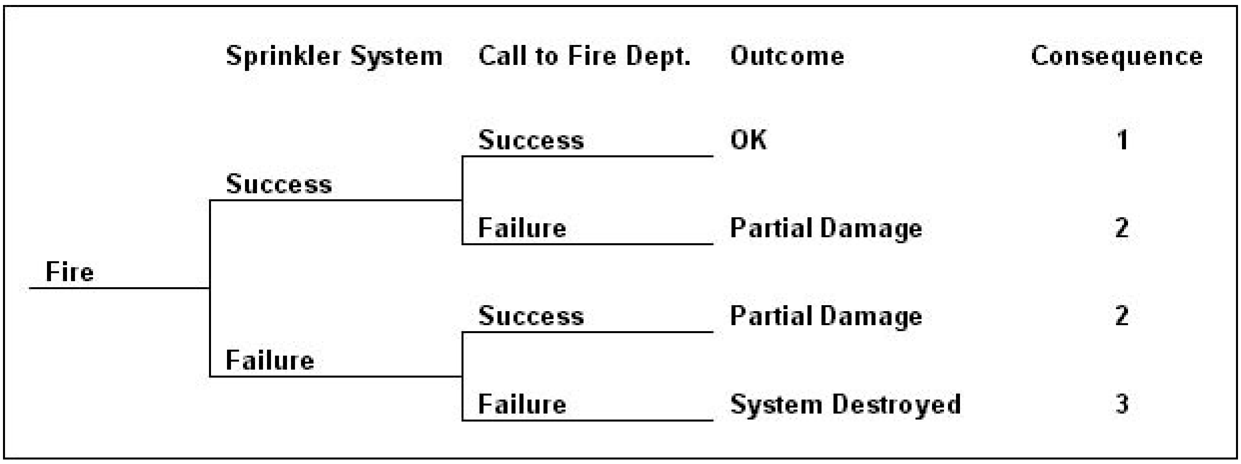
Systems to fulfil their tasks have to be defined. Maintenance and repair of components or Systems have to be considered by determining the availability and capacity of Systems. branching. The Steps in construction of an event tree are shown in fig. 4.3. 1 .5.

An event tree is a visual representation of all the events which can occur in a system. As the number of events increases, the picture fans out like the branches of a tree.

Event trees can be used to analyze systems in which all components are continuously operating, or for systems in which some or all of the components are in standby mode – those that involve sequential operational logic and switching. The starting point (referred to as the initiating event) disrupts normal system operation. The event tree displays the sequences of events involving success and/or failure of the system components.

In the case of standby systems and in particular, safety and mission-oriented systems, the event tree is used to identify the various possible outcomes of the system following a given initiating event which is generally an unsatisfactory operating event or situation. In the case of continuously operated systems, these events can occur (i.e., components can fail) in any arbitrary order. In the event tree analysis, the components can be considered in any order since they do not operate chronologically with respect to each other.

Event Tree Example A simple example of an event tree is shown below .Fig 4.3.1.5



This event tree was constructed to analyze the possible outcomes of a system fire. The system has 2 components designed to handle this event: a sprinkler system and an automated call to the fire department. If the fire department is not notified, the fire will be mostly contained by the sprinkler system. If the sprinkler system fails as well, the system will be destroyed.

The goal of an event tree is to determine the probability of an event based on the outcomes of each event in the chronological sequence of events leading up to it. By analyzing all possible outcomes, you can determine the percentage of outcomes which lead to the desired result.

4.3.1.10 Risk Studies try to estimate the risk of nuclear accidents by using analytical tools. For this purpose besides determining the failure probabilities of components and Systems, the consequences of these failures have to be evaluated. This can be achieved by combining fault tree analysis with event tree analysis.

4.3.1.11 Event tree analysis shows, in a structured form, the consequences, i.e. the course of events, of initiating events. The course of events following an initiating event will depend on whether or not the safety and protection Systems, provided to prevent a disturbance resulting in an accident as well as to limit the consequences of any accident, fulfil Their tasks. The probability of occurrence of different event sequences is determined by combining the probability of the initiating event(s) and the failure probabilities of safety installations as they are determined by fault tree analyses. Before conducting an event tree analysis the minimum requirements with respect to the availability, capacity and functionability of the safety and protection Systems to fulfil their tasks have to be defined. Maintenance and repair of components or Systems have to be considered by determining the availability and capacity of Systems. In fig. 4.3.1.4 the System state definitions for a System consisting of two sub-systems is shown as well as an Illustration of event tree branching. The Steps in construction of an event tree are shown in fig. 4.3. I .5.

4.3.1.12 As with fault tree analysis one of the main problems with event tree analysis is completeness, i.e. the identification of all possible event sequences, which result in a particular state, e.g. melting of the core in a nuclear reactor. To neglect or not consider particular event sequences can, under some circumstances, render the result of a Risk Study meaningless. In reality large and complex System will have a large number of possible event sequences resulting in a particular state. For this reason completeness very often will not be possible since the time and money available is limited. In these cases, assumptions and models of the Overall System under consideration have to be used, thus reducing its complexity and in parallel also the efforts to analyse the System.

4.3.1.13 With respect to nuclear power plants three levels of Risk Assessment are distinguished, depending on the range of investigation:

1. analyses of level I consider event sequences resulting in a state of the nuclear power plant, which could not be controlled by the safety and protection System as they are designed (e.g. core melting);
2. analyses of level 2 investigate the further course and the consequences of level I analyses as they result inside the facility (e.g. the further process of core disruption and subsequent releases of radionuclides into the Containment and the transport of radioactive substances inside the Containment will be analysed; in addition, possible ways of Containment failures will be considered as well as the magnitude of possible releases into the environment);
3. analyses of level 3 are considered with the consequences of accidents outside the facility or the site (e.g. estimation of the number of deaths and injuries in the population living in the vicinity of the facility).

The certainty of the results, gained at the different levels of Risk Assessment, very often decreases from level I to level 3 significantly. Probabilistic Safety Analysis is in general only concerned with investigations of level 1. In fig. 4.3.1.6 the steps of conducing a level 2 Probabilistic Safety Analysis for a nuclear power plant and in fig. 4.3.1.7 the schematic diagram of a general level 3 Risk Assessment is shown.

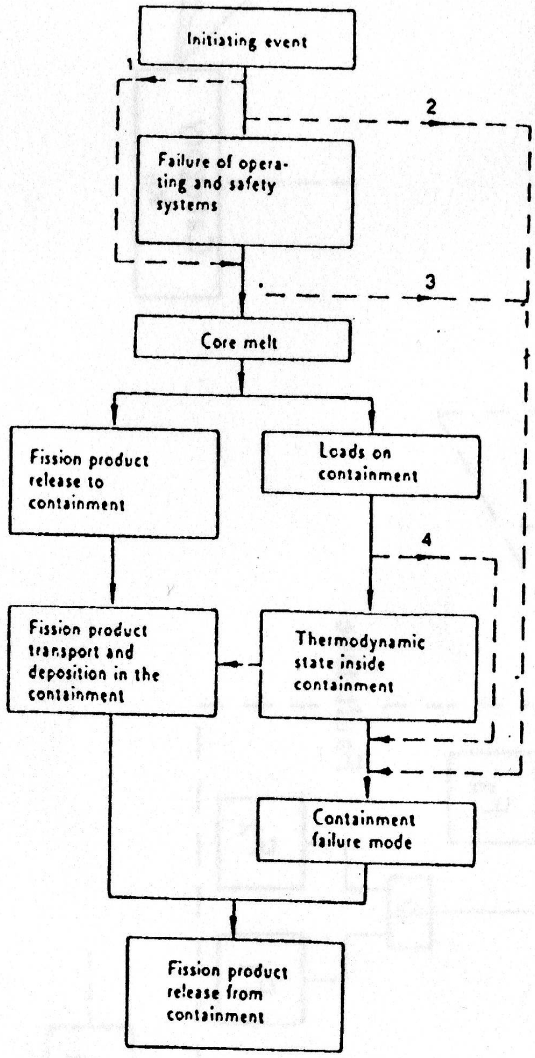


Fig. 4.3.1.6: Steps of a level 2 Probabilistic Safety Analysis for a nuclear power plant.

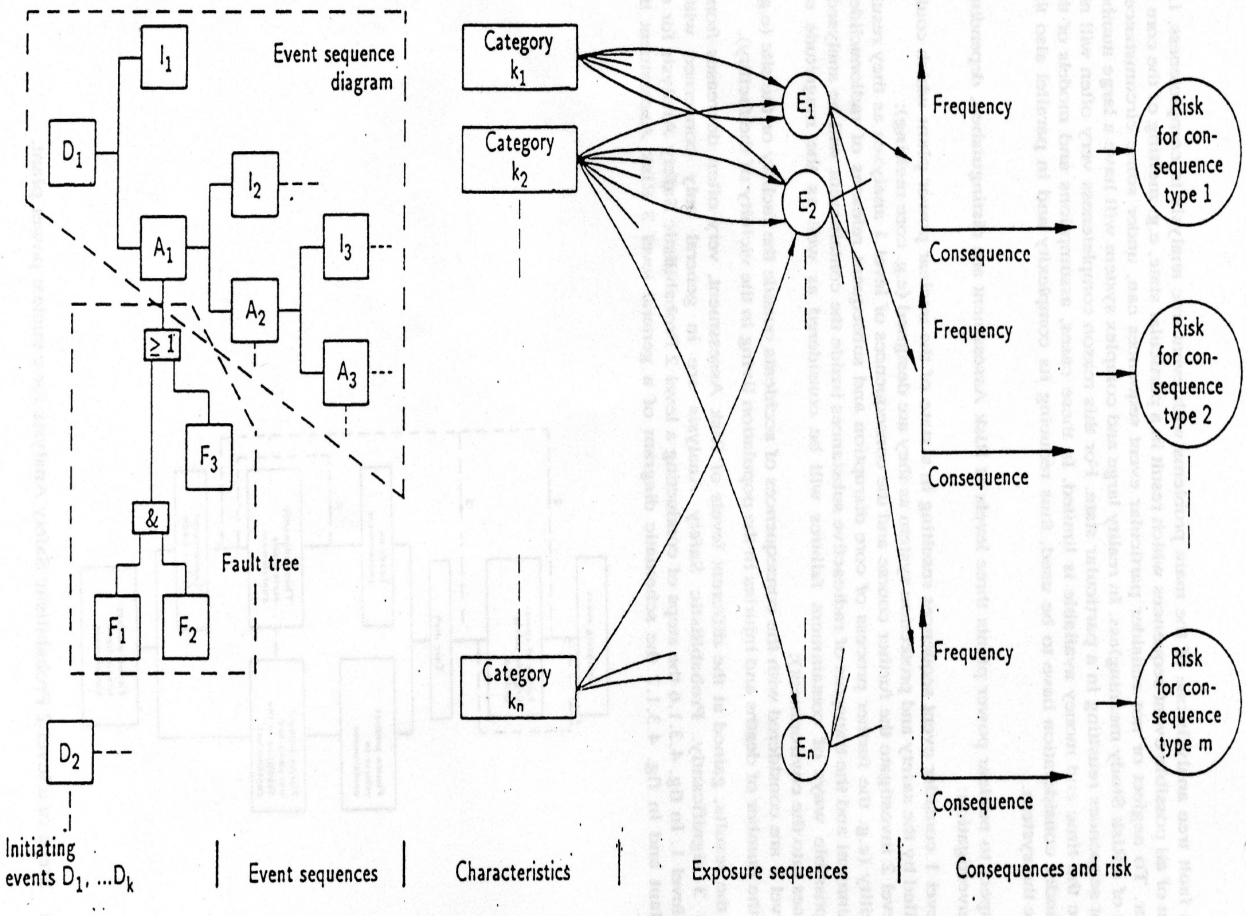


Fig. 4.3.1.7: Schematic diagram of Risk Assessment based on detailed knowledge of event and expsoure sequences.

4.3.2 Environmental Risk Assessment

4.3.2.1 Environmental Risk Assessment, as defined in this Reader, is concerned with the evaluation of general man-made hazards concerning the health and welfare of individuals, the population or the society as well as the environment. Thus, Environmental Risk Assessment can be distinguished from the evaluation of hazards due to natural events (see chapter 4.2). Using this definition, Risk Assessment of technological hazards, as described in chapter 4.3.1, forms one part of Environmental Risk Assessment which is described separately in this Reader, because the "state-of-the-art" of the assessment of technological hazards is very different, i.e. in some way much more advanced and systematized, compared to the assessment of general environmental hazards as described in the subsequent paragraphs.

4.3.2.2 In the following some examples are given of what is considered to constitute an environmental hazard:

- the health effects of exposure to ionising radiation;
- the health effects of using Chemical additives (e.g. benzene) in the fuel of automobiles;
- comparison of the health effects of using lead and benzene as additives in the fuel of automobiles;
- the health effects of a particular drug, i.e. a comparison of the side effects of the drug and the benefits of medical treatment;
- the overall risk of living at some place, i.e. in a rural or urban area;
- the probability of dying in consequence of a car accident;
- the probability of injuries or death related to mountain climbing;
- the health risks of soil, food and water contamination by harmful chemical substances;
- the health risks of producing and using organo-chlorine compounds;
- the risk of wiping out a particular animal species in some region by constructing a particular facility, e.g. a chemical plant, at some place;
- the consequences of large emissions of Chloride carbohydrate compounds into the atmosphere with respect to the global climate and the water level of the oceans; etc.

4.3.2.3 In all the above mentioned cases the evaluation of the risks involved is a very complicated and complex task, always involving a number of different scientific disciplines. In nearly all the cases the risk can only be estimated to an order of magnitude, with the range of the determined risk in general being very broad. The reasons for this are manifold, e.g. insufficient description of the problem, consideration of only parts of the problem (incompleteness), application of unsuitable models, use of unsuitable tools, incomplete knowledge concerning the processes involved, etc.

4.3.2.4 The approach of Environmental Risk Assessment in general involves the following steps:

- definition of the problem, i.e. what hazard has to be assessed and what kind of consequence or damage;

- detailed description and formulation of the problem;
- determination of the amount of harmful agent or substances produced or excising;
- determination of the emitted quality of the agent or substance into the biosphere as well as the form of the emissions (e.g. gaseous, liquid, etc.), Üie chemical composition of the releases, the spatial and temporal distribution of the emissions, etc.;
- determination of the transport and accumulation of the agent or substance in the biosphere;
- determination of the exposure pathways with respect to the agent or substance;
- determination of the affected population, i.e. the population at risk;
- determination of the exposure, i.e. the average and the maximum exposure, of the population at risk;
- determination of the consequences (health effects, late effects, teratogenic effects, etc.) of exposures;
- determination of the expected effects, i.e. number of persons and significance of the effects;
- determination of the uncertainty of each step as well as the overall uncertainty of the final estimation concerning the expected effects.

4.3.2.5 In the appendix an examples of Environmental Risk Assessment is given. It is concerned with the assessment of late health effects caused by exposure to ionising radiation as this was carried out by the International Commission on Radiological Protection (ICRP) and published in the Publication No: 60 (1990)

5 Possibilities and limitations of Risk Assessment methodologies

5.1 Risk Assessment, considered as one aspect of the overall frame of application and use of technologies, is aimed to:

a. identify and exclude extraordinary hazards concerning the health of workers, the population and the environment;

b. render it possible that the financial resources of societies are used in an "optimum" way, i.e. money will be directed lo that fields where risks could be reduced most effectively;

c. meet the need of industry and companies to use hazardous technologies in gaining profit.

5.2 Risk Assessment constitutes a balanced methodology (or concept) of four components:

1. hazard identification;
2. risk estimation;
3. risk assessment;
4. politic risk decision.

Only if all Steps of Risk Assessment are conducted satisfactorily, with consideration of the respective tasks and duties and only if all components are joined together in a consistent way with the methodology of Risk Assessment work. If, for example, political decision on risks are based more on the interest of particular social groups than on a systematic assessment of the risk, the overall methodology will fail and the trustworthiness of some or all of the interest groups affected by the problem will be lost.

5.3 Some authors, mainly social scientists, consider the methodology of Risk Assessment as inadequate to fulfil its task of constituting an objective basis for political decision making, accepted by all interest groups involved, on man-made hazards, since:

- today the procedure of hazard identification is incomplete, i.e. there is no guarantee that by the methodology of Risk Assessment all risk of a human activity or enterprise will in fact be identified, especially if these risk become important in the future;

- unknown or unidentified risks can, in principle, not be assessed; i.e. if some risks of an intended human activity or enterprise is not identified, the overall risk of the activity or enterprise will be underestimated, i.e. the methodology is not conservative;
- Risk assessment cannot be considered as a "scientific" discipline but as a procedure, integrating different approaches, philosophies, scientific disciplines and basic theorems;
- some risks will be not considered at all by definition, e.g. concerning nuclear power plants risks from natural disaster, war, terrorism, etc.;
- there is no generally accepted frame of assessment with respect to the quantification of immaterial damages, e.g. injuries, diseases, death, contamination of the environment, etc.;
- there is no "natural" limit with respect to the possible damage of a human activity or enterprise defined by the methodology of Risk Assessment - nether scientifically, economically nor politically - beyond which - if such damages cannot be excluded with certainty - the corresponding activities or enterprises will be forbidden by definition;
- Risk Assessment is not pure research or science, but is conducted with the aim to demonstrate that some activity, facility, System or technology will be safe; thus, Risk Assessment is aimed to legitimise the application of a technology. For this reason, the methodology of Risk Assessment is not free of any value judgement, but related to the particular interests of that organization which gives the money to carry out the investigations;
- most often, the questions considered by Risk Assessment, are only one part of a much larger and extensive complex of problems and interrelations; thus, a number of consequences and effects will not be considered;
- Risk Assessment will be conducted by scientists or other persons having their own subjective opinions, judgements and prejudices, because they themselves are a part of the society and are also affected by the risks they investigate; thus a seemingly objective scientifically conducted Risk Assessment - and in consequences also its results - will always be influenced by subjective factors.

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APPENDIX

Health Risks due to Exposures to Ionising Radiation 1990 Recommendations of the International Commission on Radiological Protection

A.1 Introduction

A.1.1 The *International Commission on Radiological Protection* (ICRP) was established in 1928. with the name of the International X-ray and Radium Protection Committee (IXRPC), following a decision by the *Second International Congress on Radiology.* In 1950 the Commission was restructured and renamed. In the period before World War Two (i.e. until 1939) the ICRP was mainly concerned with questions of occupational radiation exposures, i.e. with acute and late effects (cancer) of ionising radiation. After its reorganisation the ICRP additionally became more and more involved in the problems of protection of the population from exposure to ionising radiation. One reason for this was the beginning of the atmospheric atomic bomb testing at the beginning of the 50's and the resulting global exposure of the population to the radioactive fallout. Additionally the so-called peaceful application of nuclear energy for electricity production and other purposes Starts in the fifties, also exposing the worldwide population to radiation hazards. This put forward problems like genetic and teratogenic effects of ionising radiation since the exposed population no longer consists only of male adults, but also of unborn, children and pregnant females.

A.1.2 The ICRP had established a number of sub-committees to investigate particular problems of radiation protection and to formulate recommendations, which are the basis of the Recommendations as they are published by the ICRP. These published recommendations are concerned with the protection of the population, occupationally exposed workers as well as patient with respect to medical exposures. The Recommendations of the ICRP are not binding for the national regulatory and legislative authorities or national governments, but, as a rule, the Recommendations are accepted - adapted to the national circumstances - by the single countries.

A.1.3 Since 1977, when the ICRP issued its basic recommendations as *ICRP Publication No 26,* it has reviewed these recommendations annually and, from time to time, has issued supplementary Statements in the *Annals of the ICRP.* In 1990, the ICRP issued its new recommendations as *ICRP Publication No 60.* A complete revision of the 1977 *Publication No 26* was necessary, because the development since the beginning of the 80ties give strong evidence that the radiation risks have been significantly underestimated by the ICRP in its *Publication No 26.* In doing so, the ICRP had three aims in mind:

i. to take account of new biological information and of trends in the setting of safety Standards;
ii. to improve the presentation of the recommendations;
iii. to maintain as much stability in the recommendations as is consistent with the new information.

A.1.4 In the following the approach of the ICRP to estimate the health risks of exposures to ionising radiation will be described. To begin with, in label A.1.1 the historical development of the annual limit of radiation exposures concerning the population and occupationally exposed workers as the ICRP and other bodies recommend them is shown. It is obvious that over the years the annual limits have been drastically decreased, from about 100 rad $year^{-1}$ in 1920 to about 2 rad $year^{-1}$ in 1990 with respect to occupational exposures. Additionally, in table A.1.2, the risk factor concerning late effects (malignant neoplasm) caused by exposures to ionising radiation as estimated by different authors and bodies is shown. This factor gives the expected number of additional fatal cancer cases as will result by an exposure of a "normal" population to a collective dose of 10,000 person Sievert [pers Sv] during the overall life-time of all individuals of the exposed cohort. It is remarkable that the risk factor, given by the ICRP in their Recommendations, are always at the lower end of the scale and, as a rule, is increased only with a large delay, after a number of other authors or bodies had published a higher value.

Year	Annual Limit
1902	2,500 Roentgen were expected not to be dangerous to health
1920	the treshold dose, i.e. the dose below which no radiation effect will be observable, for radiologists was fixed to 100 Roentgen $year^{-1}$
1934	the annual dose limit with respect to x-rays was fixed at 50 Roentgen $year^{-1}$ by the IXPRC and at 25 Roentgen $year^{-1}$ in the US
1949	the Three-Party-Conference fixed the annual radiation dose for single individuals of the population to 3 mSv $year^{-1}$
1950	an annual dose limit of occupationally exposed workers of 0.15 Sv $year^{-1}$ was recommended by the ICRP
1953	the annual dose limit for the population was fixed at 15 mSv $year^{-1}$ by the Three-Party-Conference
1954	with respect to single individuals of the population a dose limit of 15 mSv $year^{-1}$ was recommended by the ICRP
1956	the ICRP recommended an annual dose limit for occupationally exposed workers of 50 mSv $year^{-1}$ and for single individuals of the population of 5 mSv $year^{-1}$
1959	the ICRP recommended an annual dose limit of 1.7 mSv $year^{-1}$ for the general population
1977	introduction of the ALARA-principle by the ICRP: an annual dose limit of 50 mSv was recommended concerning occupationally exposed workers, but the actual exposure have to be as low as reasonable achievable, economic and social factors being taken into account
1985	the ICRP recommended an annual dose limit for the population of 1 mSv $year^{-1}$ with exceptional exposures of single individuals up to 5 mSv $year^{-1}$ possible
1988	the German radiation protection law fixed the annual dose limit for occupationally exposed workers at 50 mSv $year^{-1}$ with the additional requirement that the maximum life-time dose do not exceed 400 mSv and fixed the annual dose limit for the population at 1.7 mSv $year^{-1}$
1990	the ICRP recommended an annual dose limit for occupationally exposed workers of 50 mSv $year^{-1}$, but with no more than 100 mSv in 5 subsequent years and an annual dose limit of 1 mSv $year^{-1}$ for the population with exceptions of higher exposures admissible in single years

Table A.1.1: Change of the admissible and recommended annual dose limits of exposures to ionising radiation.

Author or Body	Life-Time Risk of Cancer [10^4 pers Sv]
BEIR I (1972)	117 - 621
ICRP *Publication No 26* (1977)	125
UNSCEAR (1977)	75 - 175
BEIR III (1980)	77 - 266
Gofman (1981)	333 - 4255
Bertell (1981)	72 - 2100 (females)
	38 - 1200 (males)
Charles et al (1983)	18 - 1800
Schmitz-Feuerhake (1983)	100 - 400
Preston and Pierce (1987)	580 - 1800
UNSCEAR (1988)	420 - 1070
BEIR V (1990)	640 - 1160 (females)
	540 - 1240 (males)
Gofman (1990)	3200
ICRP *Publication No 60* (1990)	400
Nussbaum et al (1991)	1610 - 3330

Table A.1.2: Estimation of the life-time risk of fatal cancer in a "normal" population due to acute whole-body exposures as they are given by different authors and bodies.

A.2 Starting point of the Risk Assessment of the ICRP

A.2.1 The starting point of the Risk Assessment of health effects due to exposures to ionising radiation of the ICRP is the Statement that radiation protection has to provide an appropriate Standard of protection for man against the harmful effects of radiation without unduly limiting the beneficial practices giving rise to radiation exposures. The attainment of this aim is considered by the ICRP as not exclusively achievable on the basis of scientific concepts alone. All those concerned with radiological protection have to make value judgements about the relative importance of different kinds of risk and about the balancing of risks and benefits. Risks of exposure to ionising radiation have to be considered in comparison to health risks from other causes. The ICRP believes that the Standard of environmental control needed to protect man to the degree currently desirable will ensure that other species are also not put at risk. Nevertheless individual members of non-human species might be harmed, but not to the extent of endangering whole species or creating imbalances between species.

A-2.2 There are three main adverse biological effects resulting from the impact of ionising radiation on the human body identified by the ICRP. By the process of ionisation atoms and molecules will be changed, at least transiently, and may thus sometimes damage cells. If cellular damage occurs, and is not adequately repaired, it may prevent the cell from surviving or reproducing, or it may result in a viable but modified cell. These two outcomes have profoundly different implications for the organism as a whole. Most organs and tissues of the body are (probably) unaffected by the loss of even substantial numbers of cells, but if the number lost is large enough, there will be observable harm reflecting a loss of tissue function; this is called a *non-stochastic* radiation effect. If the irradiated cell is modified rather than killed, after a prolonged and variable delay time (latency period) a malignant condition, i.e. a cancer, may result; this effect is called *stochastic* . If this kind of damage occurs in a cell whose function is to transmit genetic information to later generations, any resulting effects, which may be of many different kinds and severity, are expressed in the progeny of the exposed person; this type of stochastic effect is called *hereditary.*

A*23 The ICRP takes the view that keeping their recommendations non-stochastic effects of ionising radiation under normal conditions, i.e. besides accidents, etc., can be excluded and that stochastic and hereditary effects can be expected to occur with a probability (or relative frequency) which is comparable with the corresponding hazard of other activities or practices, e.g. involving other carcinogenic substances. Besides fixing annual dose limits the ICRP tries lo minimize the expectable stochastic radiation effects by requirering that every radiation exposure have to be justified (on the background of risk-benefit-comparisons) and to be as low as reasonably achievable, economic and social factors being taken into account (ALARA principle).

A.3 Radiation biological assumptions considered as valid by the ICRP

A3.1 Stochastic effects of ionising radiation are not in principle identificable as such. E.g. a particular cancer disease cannot definitely be related to a specific unique cause but may have different possible causes; the best one can do is to calculate the probability of each of the different causes for induction of the observed cancer. For this reason, and because experiments with humans are not possible, to estimate the risk of ionising radiation with respect to stochastic effects indirect approaches (e.g. experiments with animals or cell cultures, epidemiological studies, biochemical and biophysical models, etc.) have to be used to gain evidence concerning the kind of effect as well as its magnitude. In most cases for economic reasons laboratory experiments on animals or cell cultures are carried out at very high doses and dose rates compared to the irradiation level, which actually occurs with the exposure of the population and workers. Therefore additional models have to be used (dose effect relationships) to extrapolate the expected effects at low doses and dose rates from observed effects at high doses and dose rates or to transfer effects, observed in one (animal or human) cohort, to another cohort.

A3.2 In addition to this the risk assessment, as carried out by the ICRP, is based on the following assumptions:

1. To correlate the exposure to ionising radiation to an effect only macroscopic quantities have to be considered, i.e. only the in the organs or tissue of the body deposited radiation energy (the average, dose absorbed by the organ or tissue absorbed dose) will be considered and not its distribution and discontinuous deposition in the organ or tissue itself.

2. In principle, two different kinds of radiation effects can be distinguished:

a, *non-stochastic (deterministic) damages*

By the impact of ionising radiation on cells, in consequence of the ionisation process, the cell will be damaged. If the subsequent repair of the cell is not successful, the cell will probably not survive or, in future, be unable to reproduce. Because in most of the organs and tissues even the killing of a large number of cells is assumed to cause no (observable) damage, at low doses of ionising radiation, no damage will be perceptible. Only at high doses, if a large number of cells are affected, will damage be observable (e.g. loss of organ or tissue function, death of the whole organism, etc.). Thus a threshold exists, below which the probability of observing damage will be zero and above which the severity of the harm will increase steeply with the dose to unity (100%). The actual value of the threshold depends on both the effect considered, as well as the individual sensitivity.

b. *stochastic damages*

If in consequence of the impact of ionising radiation the cell is only damaged, i.e. the cell is not killed and its reproduction capability is not lessened, the damage can manifest itself in the form of a mutation, either caused directly by the impact of the radiation or indirectly if the repair process is not successful. By the process of reproduction the damaged cell will reproduce, with all the resulting cells having the same mutation. After a latency period, depending on the kind of damage and organ or tissue affected, a cancer may result because the single mutated cell can be considered as the primary cause of the malignancy no threshold dose exists below which the probability of induction of a malignancy will be zero. This means that, even in the case of very low doses of radiation, the spontaneous incidence of cancer will be increased. Furthermore the severity of the harm is independent of the dose. Only the probability of induction of a malignancy will increase with the dose

3. With respect to stochastic radiation damages (cancer, hereditary, etc.) the relationship between the effect of an exposure and the dose is linear-quadratic (see fig. A.3.1). The linear component determines the dose-effect-relationship in the dose range where the exposure caused by natural sources occurs.

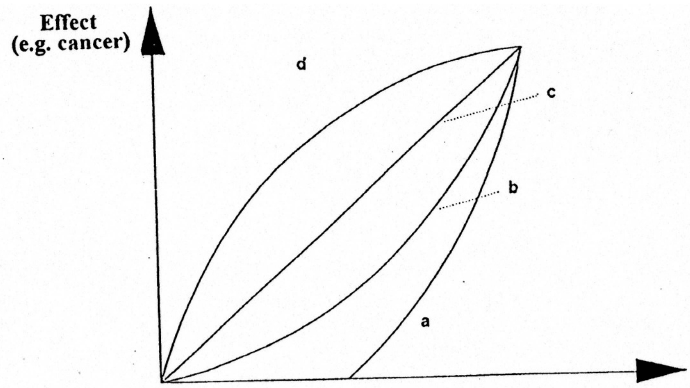

Fig. A.3.1: Different courses of the dose-response-relationships (ionising radiation - cancer). Curve a has a threshold and is not realistic for radiation protection purposes. Curve b corresponds to a linear-quadratic relationship, resulting in a relatively low risk at low doses. A quadratic curve would result in a even lower risk at low doses. A linear relationship, as used by the ICRP, is shown by curve c. Curve d is called super-linear and results in a higher risk in the low dose range compared to the linear one. This curve can be described by a linear-quadratic equation with the quadratic term being negative.

4. Different types of radiation (a-, ß-, y-radiation, x-rays, neutrons, etc.) and radiation of the same type but different energy demonstrate a different biological effectiveness which could be adequately described by the factor of the *relative biological effectiveness* (RBE-factor), see table A.3.1..

Type and Energy Range	w_R
photons, all energies	1
electrons and muons, all energies	1
neutrons, energy < 10 keV	5
10 keV to 100 keV	10
100 keV to 2 MeV	20
2 MeV to 20 MeV	10
> 20 MeV	5
protons, other than recoil protons, energy > 2 MeV	5
α particles, fission fracments, heavy nuclei	20

Table A.3.1: Radiation weighting factors w_R; all values relate to the radiation incident on the body, or internal sources, emitted from the source.

5. Different final point (e.g. percentage of the animals or cells surviving for some fixed time after the exposure, percentage of the animals demonstrating some malignancy some time after the exposure had finished, etc.) concerning the relative biological effectiveness result in the same RBE-factor with respect to the various kinds of radiation and energies.

5. A different sensitivity of various organs or tissues to ionising radiation can be expressed by specification of a *tissue-weighting factor* (see table A.3.2). For this

reason the precise definition of the target organ or tissue in the case of a whole body exposure is not needed.

Organ or Tissue	w_T
gonads	0.20
bone marrow (red)	0.12
colon	0.12
lung	0.12
stomach	0.12
bladder	0.05
breast	0.05
liver	0.05
oesophagus	0.05
thyroid	0.05
skin	0.01
bone surface	0.01
remainder[1]	0.05

[1] For purposes of calculation, the remainder is composed of the following additional organs and tissues: adrenals, brain, upper large intestine, small intestine, kidney, muscle, pancreas, spleen, thymus, and uterus. The list includes organs which are likely to be selectively irradiated. Some organs in the list are known to the susceptible to cancer induction. If other organs and tissues subsequently become identified as having a significant risk of induced cancer they will then be included either with a specific w_T or in this additional list constituting the remainder. The latter may also include other organs or tissues selectively irradiated.

Table A.3.2: Tissue weighting factors w_T. The values have been developed from a reference population of equal numbers of both sexes and a wide range of ages. In the definition of effective dose they apply to workers, to the whole population, and to either sex.

7. The RBE-factor is independent of the respective organ or tissue and the weighting factor of the tissue is independent of the type of radiation and its energy.
8. Further-weighting factors to take account of other characteristics of the particular exposure condition have not to be considered (e.g. duration of the exposure, dose rate, etc.).
9. By measuring the external radiation field and determination of its components the dose of the target organ or tissue can be calculated.
10. To calculate the dose due to external and internal exposure the so-called *reference man* can be used, this idealized man has a precisely defined build, metabolism and organism. Individual difference, in comparison to the reference man, of exposed persons will be considered in particular cases.
11. To determine the radiation risk it is sufficient to consider a Standard population, having a particular distribution of ages, sexes, etc., to which the calculated risk will be related.
12. Individually different sensitivities and particular sensitive sub-groups of the population (e.g. unborn, infants, eider people, etc.) to ionising radiation can be neglected by defining the annual dose limits.

13. The expected effects of radiation exposures at low doses and dose rates can be deduced from the effects observed in experiments at animals or cell cultures and those effects observed in reality at human, e.g. in the cohort of the survivors of Hiroshima and Nagasaki, at high doses and dose rates. For this purpose the linear dose-response-relationship have to be used with respect to stochastic effects by additional consideration of a *dose and dose rate effectiveness factor* (DDREF) of 2.

14. The model to describe the temporal development of the risk of cancer after a single exposure to ionising radiation a combination of the absolute and relative life-time risk projection model can be used (see figs. *A3.2* and A.3.3).

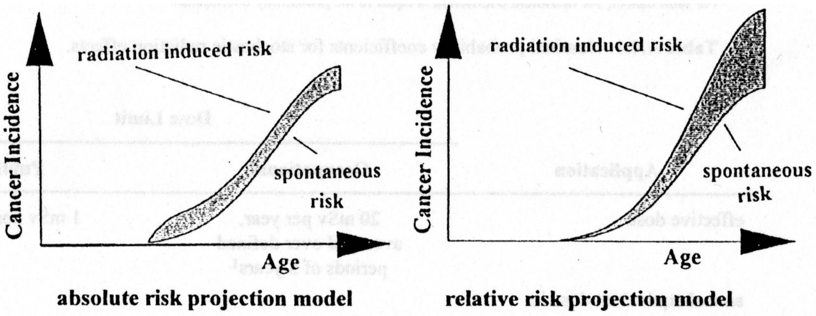

Fig. A.3.2: Schematic comparision of the absolute and relative risk projection model. The absolute projection model predicts that the spontaneous cancer incidence rate will be increased by an absolut constant factor after an exposure event during the later life (i.e. after the latency period has been elapsed). With respect to the relative risk projection model the ratio of radiation induced malignancies to the spontaneous cancer incidence will be constant after an exposure event and the respective latency period. Because, during life the cancer incidence rate will increase with age, the absolute radiation induced risk of cancer increases with age using the relative model.

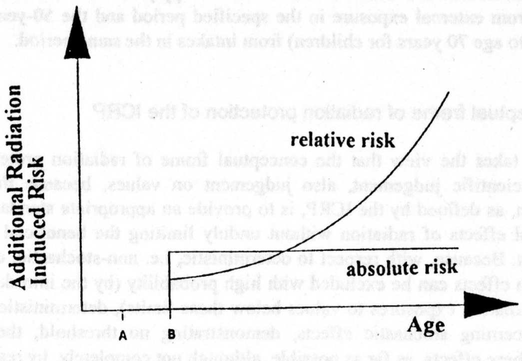

Fig. A.3.3: The additional risk of cancer after an exposure at the age of A using the absolute and relative risk projection model. The time period between A and B is the minimum latency period between induction and diagnosis of cancer.

15. By using the relative risk projection model additional competing causes of cancer induction will be considered which reduce the probability that a person will die, as a consequence of a radiation induced cancer.

The concepts of quantification of radiation exposures as they result from these assumptions are shown in tableA.3.4.

Quantity	Equation	Remarks
absorbed dose	$D = d\varepsilon / dm$	absorbed energy $d\varepsilon$ per unit mass dm [J kg^{-1}] or Gray [Gy]
absorbed dose rate	$D = dD / dt$	increase of the absorbed dose dD per time interval dt [Gy h^{-1}]
organ or tissue dose	$D_T = \varepsilon_T / m_T$	total energy ε_T absorbed by an organ or tissue of mass m_T [Gy]
equivalent dose of radiation of type R to the organ or tissue T	$H_{T,R} = w_R * D_{T,R}$	$D_{T,R}$ is the average dose of radiation of type R in the organ or tissue and w_R the radiation weighting factor (see table A.3.1) [J kg^{-1}] or [Sv]
total equivalent dose	$H_T = \Sigma_R w_R * D_{T,R}$	sum of all organ and tissue equivalent doses [Sv]
effective dose	$E = \Sigma_T w_T * H_T$	sum of organ and tissue doses weighted by the tissue weighting factor w_T (see table A.3.2) [Sv]
committed effective dose	$E(t) = \int_0^\infty E(t)\, dt$	life-time dose following an intake to the body of a radioactive material with E(t) the time dependent effective dose rate [Sv]

Table A.3.4: Concepts to quantify radiation exposures.

A.4 The ICRP concept of harm

A.4.1 In the *Publication No 26* (1977) the ICRP introduced the concept *of detriment* as a measure to describe the overall damage a radiation exposed cohort might demonstrate, due to exposure to ionising radiation. Subsequently the ICRP interpreted detriment in terms of health damages. Detriment, as defined in *Publication No 26* (1977) by the ICRP, relates to the expected number of radiation induced health effects in a particular cohort, weighted with a factor, describing the severity of the damage. This weighting factor is equal or less than l.

A.4.2 In the *Publication No 60 (1990)* the ICRP tries to redefine the concept of detriment by broadening it’s meaning, because the former approach to detriment was considered as useful but somewhat too limited. The objective was to find a quantitative way to express the combination 'of the probability of occurrence of a health effect and the judgement of the severity of that effect. Ideally detriment should be represented as an extensive quantity, i.e. one that allows the detriment to a group to be added as additional exposures occur to individuals and as more individuals are added to the group. In doing this the ICRP tries to avoid the term *risk,* because this term was considered as too descriptive by the ICRP.

A.43 The concept of detriment is used by the ICRP for several purposes. One is to assess the consequences of continued or cumulative exposures in order to recommend dose limits. Another is to compare .the consequences of different distributions of equivalent dose within the body and thence to select a set of tissue weighting factors. A third is to provide a basis for assessing the valuation of a unit of effective dose for use, for example, in the optimisation for protection within a practice.

A.4.4 The concept of detriment, as defined by the ICRP in the Publication No 60 (1990) has 4 levels: Level 1: changes which probably result in damages, e.g. ionisation in-between a cell;

Level 2: damages, i.e. adverse changes, which not necessarily have to result in adverse consequences to the radiation exposed individual;

Level 3: harm as a clinically observable adverse effect at individuals or their progeny; Level 4: detriment as a concept to combine the parameters of probability of harm, severity of harm and duration of time, until the harm will have been manifested.

A.4.5 One application of the concept of detriment of the ICRP is given by the concept of the tissue-weighting factor in Publication No 60 (1990). The objective in defining the tissue-weighting factor was to define a quantity describing the overall exposure (i.e. the equivalent dose), and which will ensure that the same detriment will be described by the same value of this quantity, ignoring which organ or tissue in particular was irradiated.

A.4.6 The ICRP considers four main components of detriment due to radiation exposures of the whole body at low doses:

1. the risk of fatal cancer in all relevant organs;
2. a specific allowance for differences in latency which result in different values of expected life lost for fatal cancer in different organs;
3. an allowance for morbidity resulting from induced non-fatal cancers;
4. an allowance for the risk of serious hereditary diseases in all future generations descended from the irradiated individual.

A.4.7 Every health effect will be multiplied by a weighting factor, depending on the severity of the damage. Concerning death of the individual and severe hereditary effects this factor is equal to 1. Concerning not necessarily fatal cancer diseases, caused by exposure to ionising radiation, this weighting factor is equal to the average ratio of all fatal diseases of the particular cancer considered to all cancer diseases of this particular type (e.g. with respect to skin cancer the weighting factor is equal to 0.01, because in 99% of all cases skin cancer is non-fatal, but can be "cured").

Concerning shortening of lifetime due to a fatal cancer disease, caused by an exposure to ionising radiation, the weighting factor is equal to the relative loss of lifetime. The product of the mortality coefficient, the weighting factor of morbidity and the weighting factor of the relative loss of life-time, is standardized for all cancers to I and is used for the calculation of the tissue weighting factor.

A.4.8 The nominal probability coefficient of mortality is used by the ICRP as the final quantity to describe the risk of radiation exposures. This quantity gives the estimated probability of a fatal cancer disease per unit of effective dose. With respect to stochastic radiation effects these coefficients are shown in table A.4.1. Based on the estimated risk of stochastic radiation effects and a comparison of this risk with risk from other causes and their contribution to the overall individual and collective risk, the ICRP in a next step defined the annual dose limits in terms of an effective dose to the population and occupationally exposed workers. These limits are shown in table A.4.2.

	Detriment (10^{-2} Sv^{-1})[1]			
Exposed Population	**Fatal Cancer**[2]	**Non-Fatal Cancer**	**Severe Hereditary Effects**	**Total**
adult workers	4.0	0.8	0.8	5.6
whole population	5.0	1.0	1.3	7.3

[1] Rounded values
[2] For fatal cancer, the detriment coefficient is equal to the probability coefficient.

Table A.4.1: Nominal probability coefficients for stochastic radiation effects.

	Dose Limit	
Application	**Occupational**	**Public**
effective dose	20 mSv per year, averaged over defined periods of 5 years[1]	1 mSv per year[2]
annual equivalent dose in		
the lens of the eye	150 mSv	15 mSv
the skin[3]	500 mSv	50 mSv
the hands and feet	500 mSv	-

[1] With the further provision that the effective dose should not exceed 50 mSv in any single year. Additional restrictions apply to the occupational exposure of pregnant women.
[2] In special circumstances, a higher value of effective dose could be allowed in a single year, provided that the average over 5 years does not exceed 1 mSv per year.
[3] The limitation on the effective dose provides sufficient protection for the skin against stochastic effects. An additional limit is needed for localised exposures in order to prevent deterministic effects.

Table A.4.2: Recommended dose limits. The limits apply to the sum of the relevant doses from external exposure in the specified period and the 50-year committed dose (to age 70 years for children) from intakes in the same period.

A.5 The conceptual frame of radiation protection of the ICRP

A.5.1 The ICRP takes the view that the conceptual frame of radiation protection necessarily has to involve, besides scientific judgement, also judgement on values, because the primary objective of radiation protection, as defined by the ICRP, is to provide an appropriate Standard of protection for man against the harmful effects of radiation without unduly limiting the beneficial practices giving rise to radiation exposures. Because, with respect to deterministic, i.e. non-stochastic, effects a threshold exists below which health effects can be excluded with high probability (by the introduction of dose limits and the limitation of radiation exposures to values below these limits), deterministic effects can in principle be excluded. Concerning stochastic effects, demonstrating no threshold, the ICRP considers it as necessary to limit these effects, as far as possible, although not completely, by reasonable measures.

A.5.2 By considering the consequences of activities and practices related to exposure to ionising radiation the ICRP balanced the related risks and benefits concerning end points, the whole society and the single individual. Risk and benefits of activities and practices, resulting in radiation exposures, need not be - and in reality are not - evenly distributed among the society. For this reason the ICRP takes the opinion that the protection of the single individual has to be considered on a case-by-case basis.

Special emphasis must be given to radiation doses, which will occur in the future by recently conducted activities and practices.

A.53 To distinguish between two different aspects of radiation protection, the ICRP defines a sequence consisting of events and situations, which will probably result in a radiation exposure of man. This sequence consists of:

radiation sources - exposure pathways in the environment - exposed individual.

The assessment of the effectiveness of radiation protection measures can focus either on the radiation source, given rise to individual doses in a particular cohort (source-related approach) or on the exposure of single individuals or groups of individuals, i.e. the individual or collective doses as they result from different radiation sources and practices (individual-related approach). Using the first mentioned approach it will be possible to decide whether or not the radiation exposure will result in an expected benefit larger than the expected detriment and whether all reasonable measures have been considered in order to limit the radiation exposure. The height and the probability of exposures of individuals can be determined as well as the number of people exposed, but not the total exposure of these individuals, because the contribution of other practices, resulting in additional radiation exposures, will not be considered. These contributions will be taken into account if the second approach is used. In this case the total exposure to ionising radiation of individuals will be determined, considering all relevant source of radiation and their corresponding contribution to the total dose. *The* calculated overall dose can then be compared with the prescribed dose limits.

A.5.4 To limit the overall exposure of individuals either the applications can be controlled (applications here means e.g. the introduction of new activities, actions or practices or the creation of new exposure pathways or the Variation of the number of individuals exposed) or intervention can be arranged (intervention here means e.g. to remove radiation sources, to modify exposure pathways or to reduce the number of people exposed). Both forms of measure, i.e. control of the application or arrangement of interventions, can be carried out on all three levels, i.e. with respect to the source of radiation, the exposure pathway and the exposed collective. The ICRP, by recommending measures to limit and reduce radiation exposures, focuses mainly on measures concerning the source of radiation, because all measures, concerning the exposure pathways or the seize of the exposed collective, are considered to result in more social disadvantages and in a lower effectiveness. With respect to medical and occupational radiation exposures measures to limit the dose on all three levels will be possible, but with respect to measures to limit the dose to the population primarily actions concerned with the radiation source are considered by the ICRP.

A.5,5 In the case of accidents, i.e. uncontrolled exposures to ionising radiation, the ICRP do not use the concept of determining the doses lo quantify the expected health detriment. Instead the concept of potential exposures is used to describe the fact that the doses, which can be expected in consequence of an accident by uncontrolled exposures, both with respect to the height of the doses and to the probability that an exposure actually occurs, will be uncertain, i.e. constitute a risk. The ICRP takes the opinion that these risks can only be limited by intervention directed to the level of exposure pathways or the size of the exposed collective.

A.5.6 The System of radiological protection recommended by the ICRP for proposed and continuing practices is based on the following general principles:

1. *Justification of practice*

No practice involving exposures to radiation should be adopted unless it produces sufficient benefit to the exposed individuals or to society to offset the radiation detriment it causes.

2. *Optimisation of protection*

In relation to any particular source within a practice, the magnitude of individual doses, the number of people exposed, and the likelihood of incurring exposures where these are not certain to be retrieved should all be kept as low as reasonably achievable, economic and social factors being taken into account. This procedure should be constrained by restrictions on the doses to individuals (dose constraints), or to risks to individuals in the case of potential exposures (risk constraints), so as to limit the inequity likely to result from the inherent economic and social judgements.

3. *Individual dose and risk limits*

The exposure of individuals resulting from the combination of all the relevant practices should be subject to dose limits, or to some control of risk in the case of potential exposures. These are aimed at ensuring that no individual is exposed to radiation risks that are judged to be unacceptable from these practices in any normal circumstance. Not all sources are susceptible of control by action at the source and it is necessary to specify the sources to be included as relevant before selecting a dose limit.

A.5.6 The System of radiological protection recommended by the ICRP for Intervention is based on the following general principles:

1. The proposed intervention should do more good than harm, i.e. the reduction in detriment resulting from the reduction in dose should be sufficient to justify the harm and the costs, including social costs, of the intervention.
2. The form, scale, and duration of the intervention should be optimised so that the net benefit of the reduction of dose, i.e. the benefit of the reduction in radiation detriment, less the detriment associated with the intervention, should be maximised.

A.6 The ICRP concept of risk

A.6.1 The concept of risk as used by the ICRP is primarily directed to the likelihood of fatal radiation effects, especially fatal cancer diseases. The ICRP assessed two kinds of risk, the lifetime risk due lo single irradiation events and prolonged exposures and the distribution of the radiation induced risk with the age at exposure. These risks constitute relative, and not absolute, quantities, depending among other factors on demographical data, e.g. the corresponding spontaneous incidence of cancer or the total mortality rate at different years of age. In the ICRP *Publication No 60* (1990) the term *risk* is used as a concept and not as a quantity; for example in the *Publication No 26* (1977) where risk is defined as a synonym of the likelihood of detrimental radiation induced effects. Thus risk (today) is interpreted by the ICRP as a quantity having different attributes and considering a number of factors, e.g. whether or not the risk is voluntarily adopted, familiarity with the consequences of the risk, severity of the consequences, duration of time between exposure to risk and perceptibility of the consequences, etc. Each of these factors of the risk "vector" can be quantified by likelihood, probability distributions or other quantities, although this will not always be as simple and unique as in the case of e.g. measurable physical quantities. The main emphasis of the approach followed by the ICRP is directed to the comparison of risks and not on the determination of the absolute value of a particular risk.

A.6.2 Risk Assessment as carried out by the ICRP and published in the *Publication No 60* (1990) for the above is not exclusively concerned with the investigation and determination of the probability of radiation induced effects, but considers further the severity of the effects, i.e. the detriment. Thus, not only the expected number of deaths due to an exposure to ionising radiation is considered by the ICRP, but also the age distribution of the exposed collective as well as the expected age distribution at time of death (due to radiation induced fatal cancer) is analysed to determine the corresponding expected average loss of life-time. This last factor (expected average loss of life-time, given in years) is one of the basic quantities used by the ICRP for the purpose of risk comparisons

A.63 In its Publication No 60 (1990) the ICRP gives the following definition of the two quantifiable risk quantities, which are considered mainly, namely:

1. Pf. the probability of each harmful effect (i). The effect will have to be specified, e.g. lethal cancer or curable cancer, severe hereditary harm; etc.;
2. $W_{\{}$: the consequence if the effect occurs. The consequence can be described in a variety of ways, indicating the severity of the effect and its distribution in time.

A.6.4 The mathematical expectation of consequence, identical to the average consequence is:

$$W = \Sigma_i P_j * W_i$$

When averaging is relevant, W a quantity which is sometimes used in the effort to express the magnitude of the "risk" by one single measure. In the collective case, i.e. the number of affected persons in a large population (N), the mathematical expectation is not far from a likely result unless the individual probability (p) of harm is very small. If the possible consequence for each individual is w = I case of harm (w = 0 in the case no harm occurs), the expectation will be:

$$W = N*w = N*(p*w) = N*p.$$

In the individual case, however, the mathematical expectation (w = p * w) is not an "expected" result, because the only possible outcomes are 0 or w measures of harm. The use of the expectation in this case masks the fact that it is composed of the two components p and w. For example, p = 10^{-5} may be the probability of losing, on average, 20 years of life because of cancer. The expectation of loss of life is then 2* I O^{-5} years, i.e. about 10 minutes. However, the real loss of life is either 0 (almost certain) or about 20 years (with a very small probability) and never 10 minutes.

A.6.5 The laying down of dose limits of exposure to ionizing radiation, in the view of the ICRP, touches on the questions conceded with the acceptance of risks by those people who are affected, i.e. the population and the occupationally exposed workers. In its *Publication No 26* (1977) the ICRP fixed the dose limits for occupationally exposed workers in a way such that the individuals exposed to the highest dose could be attributed an annual probability of death due to an occupationally radiation induced cancer of the order of 10^{-3}. This was considered as lying on the borderline of the unacceptable. The annual dose limit of the population (1 mSv) could attribute to an additional annual probability of death, caused by exposure to ionizing radiation, of the order of 10^{-5}, averaged over the whole population.

A.6.6 One of the Statements of the ICRP with respect to the consideration of radiation risks is the finding that the total probability of mortality, which integrated over the whole life is equal to 100%, will not be increased by radiation exposures. Thus, the introduction of new sources of risk do not change the life-time probability of death, but only the distribution of probable causes of death, i.e. the probability of death in each moment of life will be increased, provided the person is alive at that moment.

A.6.7 In its *Publication No 60* (1990) the ICRP considers the following factors, determining the radiation risk:

1. The total conditional death probability rate from all causes, for an average person (i.e. given that the individual is alive at every age u), is described by:

$$G_0(u) =* A * e^{B*u} + C$$

where u is the age and A, B and C are parameters which can be derived from demographic tables.

2. A defined exposure scenario (e.g. constant dose rate from age 18 to 65 years) may add a conditional source related incremental probability rate, dp/du, to the background rate:

$$G(u) = G_0(u) + dp/du.$$

This rate gives the increase of the rate of the probability of death in consequence of radiation exposures due to particular activities or practices with respect to the rest of the life after the exposure.

occurred. To calculate the increase the dose rate has to be known as a function of the age at exposure and by using also a postulated dose-response relationship. Concerning the question, whether the absolute value of dp/du has to be used or the relative value of (dp/du)/ $G_0(u)$, the ICRP requires that the equation (dp/du)/ $G_0(u)$« I has to be satisfied.

3. The unconditional incremental death probability rate is given by:

$$dr/du = S(T,u) + dp/du$$

where S(T,u) is the survival probability modified by the incremental risk due to an Irradiation, depending on the actual age u and related to the age T from which the probability is calculated. In the case of a single exposure T will be the age at the time of the exposure. In the case of prolonged exposures T will be the age at the onset of the exposure period. This quantity is used to calculate the attributable lifetime probability of death from the source under consideration, taking into account of the probability of reaching age u, by considering the likelihood of dying from other causes as well as from radiation.

4. The attributable lifetime probability of death R can be calculated as the integral of the conditional incremental death probability rate, i.e.:

R = ∫ (dr/du) du., with the integral from T to infinity

5. The probability density of the age of death, i.e. the Variation of dr/du with age, has to be used because the magnitude of the attributable life-time probability of death alone gives no information of when death will occur, being merely the probability of

dying from cancer due to one particular cause rather than dying from any other cause.

6. Given the unconditional incremental death probability rate dr/du over all ages, and the normal remaining life expectancy as a function of age, it is possible to calculate the mean loss of life-time Y in the case of death from radiation. The pair values: the attributable life-time probability of death R and the mean loss of life-time Y if radiation causes death, is the minimum of information needed to express the "incremental" risk.

7. The reduction of life expectancy, i.e. the mathematical expectation AL of the loss of lifetime due to a particular exposure pattern is given by:

$$\Delta L = R * Y.$$

A.7 Literature

1. ICRP Publication No 22 (1973): Implication of Commission Recommendations that Doses be Kept as Low as Readily Achievable. Pergamon Press, Oxford
2. ICRP Publication No 26 (1977): Recommendation of the ICRP. Annals of the ICRP, vol I, no 3, Pergamon Press, Oxford
3. ICRP Publication No 27 (1977): Problems Involved in Developing an Index of Harm. Annals of the ICRP, vol I, no 4, Pergamon Press, Oxford
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