Critical facilities safety

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***Abstract*—** The paper describes the critical facilities safety. On the basis of principles of strategic integral safety management in the dynamically variable world it gives historical development of concepts of engineering trade-off with risks and it shows their criticalities with regard to public assets obtained by the Multiatribute Utility Theory. It presents results of deep research, i.e.: model of work with risks; process model for ensuring the critical facility safety (five steps based on application of All-Hazard Approach and approach Defence-In-Depth); process model of critical facility management during its life cycle with six processes and their sub-processes; and programme for critical facility safety upgrading in a context of integral safety directed to existence, security and development of humans.

***Keywords*—** Critical facility, critical facility safety concept, risk, safety, safety management, safety culture.

I. Introduction

The main goal of all human effort is ensuring the human life, i.e. all human needs, assets, interests, and wishes. These wishes are fulfilled by intangible and material goods that have utility values. Unfortunately, in the world there is not just a human society, but also other systems, which are not subordinated to the human society. Therefore, conflicts originate, e.g.: man vs. the environment; technology vs. the environment; man vs. techno-logy; man vs. man, man vs. computer etc. Because the human kind is based on its education, as well as in the present case, it needs to realize that, i.e. in a given situation it is obliged to use the knowledge, which accumulated science and historical experience of life, which shows that there is a limit for the activities of the humans, which cannot be exceeded, in order to prevent the destruction of mankind.

The starting point is to accept the need for the co-existence of several important systems (mainly systems including the environment, the technologies and humans) and search conditions and ways of controlling them. The sustainable development strategy is comparable with other systems of values, which do not have the final form, e.g. the system of human rights and freedoms. It leads to ensure the highest attainable quality of life for the present generation and to create conditions for quality of life of future generations, even knowing that the ideas of the quality of life of future generations can be compared to our different. The man knew during his development that for his life and development he needs the nature and a number of other assets. During the human history he understood that:

- the most valuable asset for him it is his existence, security and development potential,
- his living world safety is disturbed by harmful phenomena, called disasters.
- From the evaluation of credible data, knowledge and experience, e.g. summarized in [1], it follows that the human knowledge and abilities are:
- small to avert disasters, which are the manifestation of the evolution of the planetary system of the Earth,
- adequate to mitigate the impacts of disasters, which are the manifestation of the evolution of the planetary system of the Earth,
- sufficient to prevent disasters that are associated with the activities of humans and with the development of human society.

To use the knowledge and skills the humans consciously create a comprehensive system tool, which is called the ***safety management*** and also specific targeted tools to deal with emergency and critical situations, which are emergency management and crisis management; in the professional literature they can be found, as well as other tools such as disaster management [2]. For qualified management of entities, according to the present knowledge and experience it is considered a strategic safety management of entities in the dynamically varying world, which means the skilled management of disasters [2], which is based on the approach of "All-Hazard-Approach" that was introduced by FEMA in 1996 [3] and it is used by EU and OCHA [1], [2]. The set of disasters that threaten the Europe now and in the near future is given and characterized in [2].

Having regard to the complexity, many disciplinary and the interdisciplinary nature of the solved problems, understanding of the situation and finding the solutions for the humans´ security and development, the critical facilities safety is based on the systems approach, a comprehensive concept of safety and proactive way of safety management, because the world / environ / space in which they are located is dynamic, i.e. it is variable in the space and time in particulars and as well as in a whole [1], [4].

On the basis of current knowledge and experiences the reasonable human negotiates with the risks so that

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systematically carries out preventive, mitigating, reactive, and recovery measures and activities in order to avert unacceptable impacts that affect him and cause the losses to both, the humans and the public assets, which humans need for their life. Because of human knowledge, capabilities and possibilities are limited in the subject area, so on the basis of the experience the humans are constantly preparing to cope with the situations, which are caused by an occurrence of a variety of disasters, i.e. phenomena, with harmful impacts on them and on their vital assets.

The aim of human effort is to construct the facilities, i.e. the technical works that fulfil the prescribed functions after specified time period and do not threaten human lives and health and the environment, i.e. they are safe. In order to ensure the safety of these facilities, the humans have been created since the beginning of the cultural evolution of the human species the legislation, technical standards and norms. They are also processed the procedures of good practice in cases in which there is not enough data for the compilation of standards or norms. At each stage of the development, the legal rules (directives, regulations) of a different legal force reflect the level of knowledge and experience of humans and in a case of facilities the company that is their originator. It is necessary to consider that norms and standards reflect the know-ledge level at the time of their origin; i.e. they become updated with time.

II. THE DEVELOPMENT OF MANAGEMENT AND TRADE-OFF WITH THE RISKS

The basis of human effort in creating a safe space is to handle (tame) with risks. The term "*risk*" has its origin in the Middle Ages and our present knowledge about the trade-off with the risks has been systematically collected since the 1930s. The acquired knowledge and experiences have been gradually applied in risk management and designated measures and activities have been introduced gradually into the practice by engineering disciplines [5], [6]. In the present work, the risk is seen as the potential that a given action or activity (including the option of doing nothing) originates losses, damages and harms (the undesirable outcome). In today's practice, it is used the five concepts of risk management and risk engineering, i.e.:

- classic risk management and classic risk engineering,
- classic risk management and classic risk engineering involving the human factor,
- risk management and risk engineering focused on security (security management and security engineering),
- risk management and risk engineering focused on safety, i.e. on such control and trade-off with risks, that ensure both, the secured facility and its safe surroundings,
- risk management and risk engineering focused on the safety of system of systems (SoS)

[5], [6], Figure 1. It is obvious that the more advanced the concept of the use, the higher are the demands on the knowledge, the tools, time, finances, qualifications of personnel, etc. Therefore, it is necessary to choose the concept according to the targets in the field of safety [7].

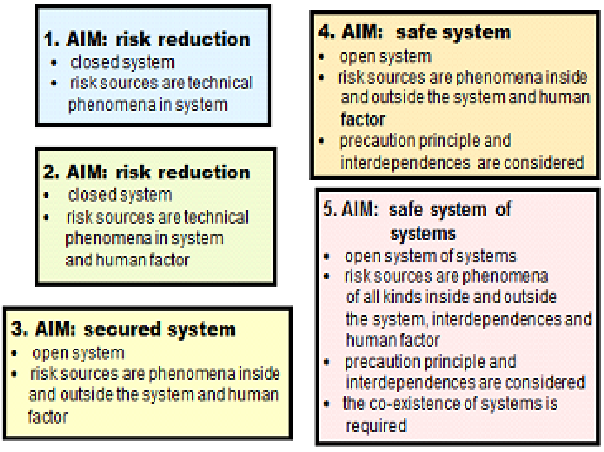

Fig. 1 concepts of risk management and engineering trade-off with risks and their goals, arranged in chronological order according to the time of their introduction to engineering practice

It is also necessary to consider that it is reality that not a use of the most advanced concept, i.e. concept of system of systems safety, does not guarantee negligible criticality, i.e. absolute safety [7], Figure 2.

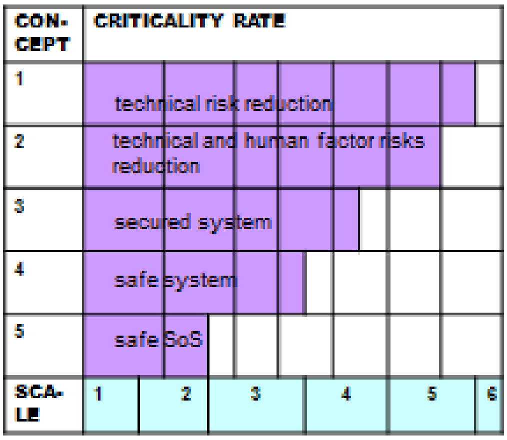

Fig. 2 criticality rates of concepts described in Figure 1 obtained by application of the MUT theory [7]

For each concept of risk management and risk engineering it was developed a certain set of standards and norms for its use in practice, [6], which amends and supplements in conjunction with the development of knowledge. Due to different assumptions of concepts the results of their application in practice are not the same. In practice the basis is the awareness of the targets of the work with the risks, i.e. whether the critical facility comprehended as a system to be a secure system or a safe system.

Since the accident, the Three Mile Islands in the critical facilities it is used the target "safe object". Basic terms from safety domain specified for the critical facilities are listed in [1], [2]. On their basis and in accordance with the concepts of the UN [8], the OECD [9],[10], and the EU [11] it holds: *secured critical facility* is a system that is protected against all disasters, the sources of which are inside and outside the system, including the human factor; and *safe critical facility* is a system that is protected against all disasters, the sources of which are inside and outside the system and it does not affect its surroundings in its normal, abnormal and critical conditions. From reality system concept the interdependences that are connected with linkages and couplings also belong to disasters.

III. CONCEPT OF CRITICAL FACILITY SAFETY

The safety is a set of anthropogenic measures and activities, which lead to ensure security and development. Since the world is dynamically changing, so the management of the safety of critical installations is focused on priorities. In the first place, it means the application to access All-Hazard-Approach [3] in the form described in [2], determining the hazards posed by individual disasters, and according to the assessment of the size of the threat from real disasters and vulnerabilities of a site and of critical facility against real disaster the separation of disasters into the following groups:

- the disasters, which cannot have impacts on a critical facility,
- the disasters that have only an acceptable impacts on a critical facility, for which we use the designation “relevant disaster”,
- the disasters that have on a critical facility impacts that are manageable at performance of the prepared prevention and mitigation measures, for which we use the designation “specific disaster”,
- the disasters that have an unacceptable impacts on the critical facility and, therefore, it is necessary to carry out essential preventive measures in the field of technical, organizational, legal and educational and it is necessary to have the possibility to activate all of the resources and the means to cope with their impact and jump-start further development, for which we use the designation “critical disaster”.

The last mentioned disasters have the potential to cause extreme emergency situations and for their defeat it is necessary to use the tools for crisis management.

Problem areas in safety management according to [1, 4] are in 14 different sectors, the list of which is in quoted papers. The strategy for ensuring the security and sustainable development of the critical facility consists in:

- the application of the system and proactive management, which relies on the knowledge and experience obtained for the critical facility from qualified data,
- a qualified trade-off with the risks in a benefit of security and sustainable development of critical facility, i.e. to build the critical facility as safe system,
- settlement of risks by help of prevention, mitigation, insurance, reserves, preparedness for response and recovery, and compilation of a plan for trade-off with unforeseen situations (with contingency plan),
- the application of the correct procedure, in which the interconnected safety management, emergency management and crisis management,
- building a program to increase the safety in critical facility and in its surroundings,
- the determination of the assessment the safety rate in sense of effectiveness of the secured system (indicators),
- the fulfilment of the program by linked interconnected projects + fulfilment projects by linked interconnected processes,
- directly specified allocation of tasks and responsibilities to all concerned,
- the implementation of the relevant activities and measures, that is associated with a qualified and consistent monitoring.

Realisation is implemented by specially processed terms of references [4] at critical facility designing, construction and operation, i.e. the use of five steps models for critical facility safety ensuring, Figure 3 [12] that was compiled with regard to results given in [13].

IV. MANAGEMENT OF SAFETY OF CRITICAL FACILITIES DURING LIFE CYCLE

As it was mentioned in the foregoing paragraph the basic principle of critical facility safety ensuring is the qualified interconnection of technical, organizational, financial, personal, social, knowledge domains; and clear roles and responsibilities of all those involved. The safety management system of critical facility, therefore, covers a number of areas, i.e. technical, military, legislative, financial, economic, social, ecological, educational, research, etc. In the field of safety, in terms of current knowledge and current concepts of sophisticated security systems, the tasks have all participants. The tasks of each participating and their interconnection in various situations are prescribed by the laws, moral and other standards and norms.

In the framework of the strategy for ensuring the security and sustainable development [1] it is necessary in a critical facility to set up:

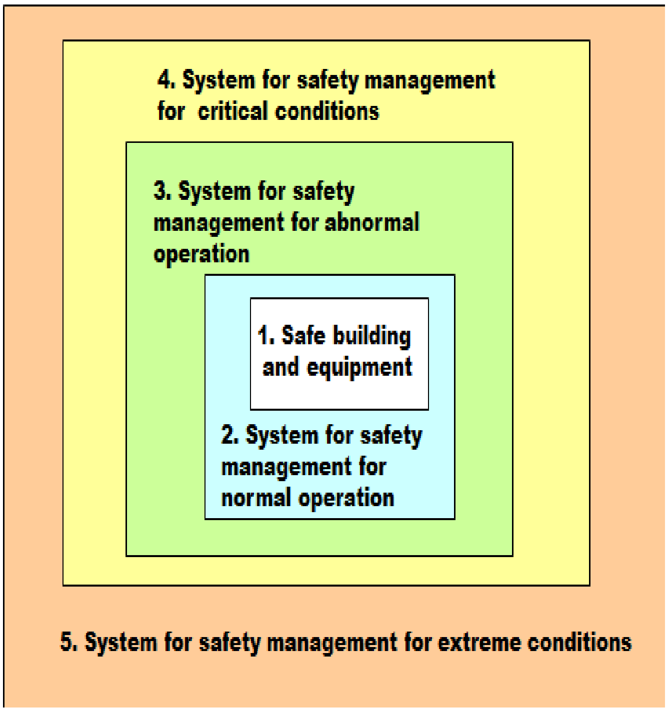

Fig. 3 five steps model for complex critical facility safety management

- a program for increase of the safety of critical facility,
- rates for the assessment of the level of safety in terms of the efficiency of the security system (e.g. indicators or threshold values of safety functions),
- a program to ensure the safety that is filled by interlaced projects,
- projects filled with interlaced processes.

The critical facility management tools that ensure the safety and the development of a critical facility, i.e. in other words, the conservation and protection and development of the protected assets [1] are:

- coherent management system involving the management of strategic, tactical and operational, which is based on the qualified data, expert assessments and good methods of deciding,
- education and training of employees,
- science, research, and TSO (the professional organization to ensure professional support to the operator of a critical facility and to public administration),
- specific education to technical and management personnel,
- technical, medical, environmental, social, cyber and other standards, norms and regulations, i.e. the tools for the control of processes, which can or could lead to the occurrence of (the origination of) a disaster, or to amplify its impacts,
- regular audits and inspections,
- the system of critical facility co-operation with the public administration, with organizations in the territory and with organizations that use similar technology,
- security units for defeat of emergency situations,
- components and systems for defeat the critical situations (i.e. after all ways ensured continuity management and crisis management),
- security, emergency and crisis planning.

So that the procedure may be correct, it is necessary to use the tools competently, i.e.: to use the documents obtained on the basis of the qualified data that meet the requirements for representative data files (completeness, valuation and settlement of random uncertainties, settlement of vague-ness (epistemic uncertainties) in the data using a specific mathematical approaches) and apply correct methods of decision-making, which are adequate to the problem, which will be decided.

The uncertainty is related to the scattering of observations and measurements. It can be incorporated into the assessment and prediction using the apparatus of mathematical statistics. ***The vague-ness (epistemic uncertainty)*** is associated with both, the lack of knowledge and information, as well as with the natural variability of the processes and events that trigger disasters. ***For processing and consideration the epistemic uncertainties the tools of mathematical statistics are insufficient and it is necessary to use a different, more modern mathematical apparatus that provide such as the theory of extreme values, the theory of fuzzy sets, theory of fractals, theory of dynamic chaos, the selected expert methods and suitable heuristics using the possibility theory or complexity theory*** [5].

Data on epistemic uncertainty follows from the fact that the data are incomplete, non-homogeneous (i.e., their accuracy depends on their size, or on the time of the occurrence) and unsteady. They have considerable variance and are loaded with random and sometimes systematic errors, the distribution functions of which are usually not possible to determine. This means that for:

- strategic (long-term) management of the critical facility that is focused on safety management, it is necessary to ***use the verified data files, proven methods for data processing and proven methods for decision making,***
- tactical (medium-term) management of the critical facility, which is aimed at readiness a routed to cope with the problems associated with emergency situations (natural disasters, accidents, etc.) in a critical facility, it is possible to use ***less accurate data, data processing method and methods of decision-making*** (less accurate process models, software, estimates, etc.), since each emergency situation is unique due to the variable conditions of its formation and changes in the availability of resources, the forces and capabilities of the organization on the reaction,

- operational (short-term) management, which decides in the time constraints and at the lack of data (response), it should be ***on the basis of acquired knowledge and experience to use targeted learned and trained procedures*** (e.g. processed in the form of case studies), because rapid response is desirable.

On the basis of current knowledge summarized in the works [1], [4]-[6] it should be noted that each of the targeted management (goal is security and development or intermediate objectives such as competitiveness or just survival) needs to be based on high-quality work with risks, that is shown in Figure 4; qualified cope with risks at the current level is described in work [5].

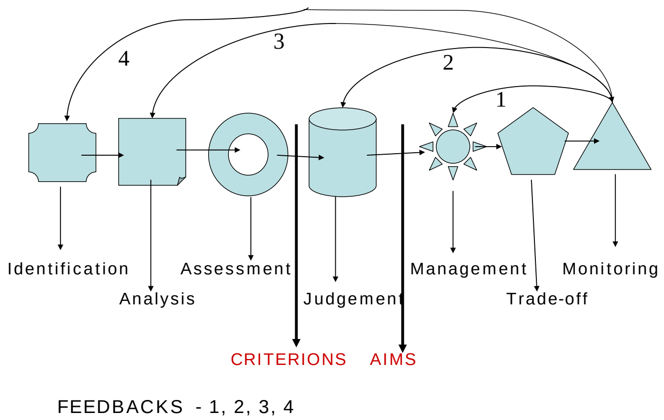

Fig. 4 basic procedural model showing the work with the risks. Criteria are conditions which determine when the risk is acceptable, conditionally acceptable or unacceptable. The objectives are the formulations, that denoted: the limit to which we want to reduce the risk; rate of security of a system; or rate of security of a system and its surroundings. Arrows (1, 2, 3 and 4) indicate the feedbacks, which are applied when the risk is unacceptable

From Figure 4 it is obvious, a major role of monitoring. In the event that it is established that the risk is unacceptable, it is necessary to make changes, as indicated on the feedback on Figure 4. Because the changes require resources, forces and means, so on the basis of ensuring the cost-effectiveness firstly it implements feedback 1, and only when it is not desirable, it realizes the feedback 2; after the feedback 3, and when, even after it is not a desirable outcome, so feedback 4. In the case of the occurrence of extreme phenomena with disastrous impacts it is immediately implemented the feedback 4.

The safety and risk together in some way related (in more detail in [1], [4]-[6] and in the works that are cited in them), but they are not complementary phenomena. On the basis of current knowledge, summarized in the works [1], [4]-[6], [15], the safety management system (the so-called SMS) of a critical facility is based on the process management and it includes the organizational structure, responsibilities, practices, rules, procedures, and resources for determining and implementing the prevention of disasters, or at least mitigating their un-acceptable impact in the territory. Usually it refers to a number of questions, inter alia, the organization, workers, the identification and assessment of hazards and risks resulting from them, the management of the organization, the management of changes in the organization, emergency and crisis planning, monitoring the safety, audits and reviews [1], [15].

On the basis of the above cited works, the SMS of critical facility consists of processes:

1. Process of concept and management, which is further divided into six sub-processes, which ensure: the overall concept; partial safety objectives; leadership / management of safety; the safety management system; the staff, which is further divided into sections: human resources management, training and education, internal communication / awareness, working environment; and review and evaluation of the implementation of the objectives in the safety.
2. Process of administrative procedures, which are further divided into five sub-processes, which ensures: identification of hazards from potential disasters and risk assessment; documentation; procedures (including work permits); the changes; safety in conjunction with the con-tractors; and supervision under safety of pro-ducts.
3. Process of technical issues, which are further divided into six sub-processes, which ensures: research and development; design and assembling; inherently safer technical and technological processes; industry standards; storage of dangerous substances; maintenance of the integrity and maintenance of equipment and buildings.
4. Process for external cooperation, which is further divided into three sub-processes, which ensures: cooperation with the administrative authorities; cooperation with the public and other stakeholders (including academic institutions); and cooperation with other enterprises.
5. Process of the emergency preparedness and response, which is further divided into three sub-processes, which ensures: planning of internal (on-site) preparedness; facilitating the planning of external (off-site) preparedness (to which the public administration corresponds); the coordination of the activities of the depart-mental organizations at emergency prepared-ness and response.
6. Process of reporting and investigation of accidents / accidents almost, which is further divided into three sub-processes, which ensures: reports on accidents, incidents, near-misses and other lessons learned; investigation of near-misses, incidents and accidents; and responses and follow-up after the incidents and accidents, including the application of lessons learned and information sharing. Processes

must be coordinated so that they are targeted to the objective set, i.e. the safe operation of critical facilities.

On the basis of analyses of the existing safety management systems, which are described in the professional literature, for which the data are summarized in the works [1], [4]-[6], [15], and in particular the knowledge collected by the OECD [9], [10], [16], [17] the author compiled by the method of analogy to existing safety management models the general process safety management system of real entity and she verified it on the data collected in the archive [18], and by the method of analogy she has transferred to critical facility, Figure 5.

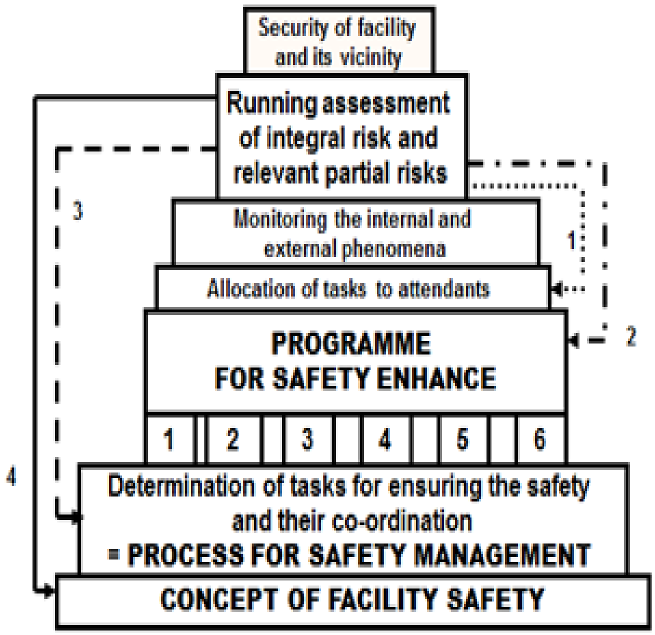

Fig. 5 process safety management model of a critical facility. Black block specifications the essential processes of the entity; the dotted line — feedback 1, dash-dot line — feedback 2 dashed line-feedback 3, full line – feedback 4

In Figure 5 it is evident basic role of concept of facility safety. It specifies the essential processes of a critical facility, which predispose a safe critical facility, i.e. its existence, safe operation and development. Then there follow the sequential steps aimed at the security and development of the entity. As the entity and it's environ dynamically develops it considers with corrections and changes. In case of the need for corrective measures there are indicated the basic feedbacks, by which it is corrected the set of measures and activities; the dotted line - feedback 1, dash-dot line - feedback 2 dashed line-feedback 3, full line - feedback 4. Be-cause the changes require resources, forces and means, on the basis of ensuring the cost-effectiveness, there is realized in the first the feed-back 1, and only when not desirable, it realizes the feedback 2; after the feedback 3, and when, even after it is not a desirable outcome, so feedback 4. In the case of the occurrence of extreme phenomena with disastrous impacts, it is immediately implemented the feedback 4.

The safety management system (SMS) of a critical facility is based on the concept of prevention of disasters, or at least their serious effects [1], [9], [10], which includes the obligation to establish and maintain a management system in which they are taken into account the following issues:

- roles and responsibilities of persons participating in important hazards management on all organising levels and in ensuring the training,
- plans for systematic identification of important hazards and risks connected with them that are connected with normal, abnormal and critical conditions, and for assessment of their occurrence probability and severity,
- plans and procedures for ensuring the safety of all components and functions, namely including the object and facilities maintenance,
- plans for implementation of changes in territory, objects and facilities,
- plans for identification of foreseeable emergency situations by systematic analysis including preparation, tests and judgement of emergency plans for response to such emergency situations,
- plans for continuous evaluation of harmony with targets given in safety concept and in the SMS, and mechanisms for examination and performance of corrective activities in case of failure with aim to reach determined targets,
- plans for periodic systematic assessment of safety concept, effectiveness and convenience of the SMS and of criterions for judgement of safety level by top workers group.

The safety of critical facility is a matter for all stakeholders, i.e. the executives, employees, even persons accidentally present. In this context, talking about ***the so-called golden rules of all participating*** [1], [9], [15], which are:

- according to their possibilities by application of preventive measures to avert disasters and or at least their unacceptable impacts, to ensure preparedness for capability to defeat the unacceptable impacts on protected assets (the interests) of a critical facility and effective response of the critical facility,
- to communicate and to cooperate with others interested in all aspects of prevention, preparedness and response of critical facilities,
- to know the hazard from disasters and possible risks in critical facility and in its surroundings,
- to implement and respect the safety culture, which is respected and enforced by all stake-holders in all circumstances,
- to establish the safety management systems, to monitor and if necessary to correct their activities,

- to use the principles of inherent safety at project, the design and operation of objects and their equipment,
- carefully to drive the changes in critical facilities,
- to be ready to cope with all the disasters that may occur,
- to help others interested at fulfilment of their roles and responsibilities,
- to carry out continuous improvement of safety,
- to work in conformity with the safety culture, safe practices, and training,
- to strive constantly for all awareness and provide information, and to provide feedback to managers,
- to strive for the development, strengthening and constant improvement of the concept of safety, regulations and directives,
- to lead and to motivate all other stakeholders in order to fulfil their roles and responsibilities,
- to know the risks within their own sphere of responsibility, appurtenant to plan measures for its proper management,
- to use of appropriate and coherent policy of planning and follow-up activities,
- to be aware of the risks in critical facility and to know what to do in case of their realization,
- to participate in emergency planning and response.

Safety culture means that the man in all his roles (executive, employee, citizen or victim of the disaster) observes the principles of safety, i.e. he behaves so that alone prevented the realization of the potential risks and when it becomes a participant in the realization of the risks, to contribute to an effective response, stabilization of the protected assets (interests) and their recovery and to kick off their further development. An effective safety culture is an essential element of safety. It reflects the concept of safety and is based on the values, opinions and discussions of key management personnel of the organization, and their communication with all stakeholders. It is a clear commitment to actively participate in addressing issues of safety and advocates that all participants did so safely and to comply with the relevant legislation, standards and norms. Rules of safety culture must be incorporated into all activities in a critical facility. Their basis is not the concentration on the punishment of the offenders / originators of errors, but the lessons learned from the mistakes and the introduction of such remedial measures, in order to not repeat mistakes or at least significantly reduced the frequency of their occurrence.

V. CONCLUSION

Analysis of the current situation shows that we can systematically handle a range of undesirable processes, i.e. defects and failures that we can detect in advance. Sometimes, however, there is a mutual interlocking a series of seemingly unrelated factors, and as a result of non-linearity in the system there are originated very atypical accidents. Analysis of accidents: breaking plateau Alpha in 1988 in the North Sea; the warehouse of aviation kerosene crashes in Buncefield 11. 12.2005; maritime, railway and unexplained air crash in recent years; the accident at the Fuku-shima is 11. 3.2011 (note – it did not respected calculated scenarios of accidents), showed that the number of experts is affected by the operational requirements of the blindness and after fulfilment of the norms and standards to see the remaining risks, or the risks associated with different bindings and couplings with the surroundings. For example, a simple comparison of intervals used in probabilistic assessments shows that: the interval (μ-σ, μ+σ) covers 68.5% of cases; the interval (μ -2σ, μ+ 2σ) covers the 85.4% of cases; and the interval (μ -3σ, μ+3σ) covers 99.8% of cases [4].

Therefore, we permit that complex systems to which surely we include critical facilities, are for various reasons from time to time in an unstable state and they are formed an organizational accidents, cascade of failures without apparent cause, i.e. we recognize the random and epistemic (knowledge) uncertainties in their behaviour. For the protection reasons we are looking for a solution of response for cases that cannot be revealed by the probabilistic approaches and we build for them, alternative sources of water and energy, specific response systems and specific training of rescuers.

To achieve the desired level of safety it is necessary well manage and properly decide. Good management and good decision making is possible only when we have good data, and we can take advantage of the tools that we have available. The data: must be correct, i.e. it is known their size and accuracy; must have explanatory power for the problem, i.e. they must be validated. The data files must be representative, i.e.: complete; contain the correct data; have a sufficient number of data; the data must be spread homogeneously throughout the reference period and must be validated. In the application of models must be properly considered random and epistemic uncertainties in the data.

It should be noted that in the real world we work at ensuring the safety of critical facilities non-trivial problems, i.e.: there is more protected assets, the objectives of which are conflicting; assets varies in time and space; and the environ, in which the assets are, i.e. the human system, is in dynamic development.

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