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Application of Quantitative Analysis to Develop a Methodological Approach to the Analysis and Assessment of the Risk of Accidents at Industrial Enterprises with Chemically Hazardous Sites

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Abstract. *The aim of the work is to present the use of quantitative analysis for the development of a methodological approach to the analysis and assessment of the risk of accidents at enterprises with chemically hazardous facilities (CHS) of the Republic of Kazakhstan. The stage-by-stage application of quantitative analysis for the purpose of a comprehensive assessment of the security management system of an enterprise with chemical weapons is considered. At the same time, the assessment is made based on the specific analyzed circumstances, taking into account the features of the technological production process, clarification and updating of data on the main dangers of accidents, justification and optimization of organizational and technical measures used at enterprises with chemical weapons. The studies carried out made it possible to form clusters and proceed to the development of sets of criterion parameters that describe the indicators of the danger of the risk of accidents and accidents and the vulnerability of the working personnel of an industrial enterprise from a chemically hazardous facility.*

Keywords: *process safety management system, quantitative analysis, accident, incident, chemically dangerous object, cluster, criterion parameter, emergency situations, impact analysis, sensitivity analysis.*

Introduction

In many cases, the assessment of the risk of accidents at chemical enterprises is carried out from the point of view of studying the factors influencing the occurrence of an accident, separately, without taking into account their interaction. For the most part, attention is focused on the physicochemical and toxic properties of hazardous chemicals, while the issues of reliability and safety of the technological processes themselves, where these substances are used, if considered, are considered separately. These circumstances do not allow for an objective and comprehensive analysis of occupational risk, since certain aspects of it remain unaccounted for.

The development of risk management systems in international practice, including in the field of preventing the consequences of man-made emergencies (ES), requires a systematic approach when taking into account and studying various factors affecting labor safety.

The research group is working on the creation of a methodological approach for calculating the risk of accidents at CHS of enterprises of the Republic of Kazakhstan with its further integration into the standard process of a systemic comprehensive assessment of labor safety. One of the stages of the study is to conduct a quantitative analysis to assess the risk of accidents at industrial enterprises with CHS. The results of these studies made it possible to form clusters and a set of criterial parameters included in them in order to determine the operability of the industrial safety management system at an enterprise with chemically hazardous sites.

Question theory

Quantitative risk analysis, or probabilistic risk assessment, is a full-scale methodology that has been used by the research team as a tool for comprehensive risk assessment of industrial plants with CHSs in order to reduce the likelihood of accidents and incidents. Quantitative risk analysis is typically performed in four steps, from hazard identification

through frequency quantification and impact analysis to relative or absolute risk measurement.

In the context of this work, the task of quantitative risk analysis is to determine the numerical impact of changes in factors affecting the safety of the production process of an enterprise, the effectiveness of the functioning of the security system of an enterprise with CHS as a whole.

Quantitative risk assessment allows us to determine:

- the probability of achieving the ultimate goal – trouble-free operation of the enterprise with CHSs;
- the degree of impact of the risk on the operation of the enterprise with CHS and the amount of unforeseen costs and materials that may be needed;
- risks requiring prompt response and greater attention, as well as the impact of their consequences on the performance of an enterprise with CHSs;
- actual costs, estimated completion dates for restoration work.

In the process of risk measurement, in order to select a critical level of risks to be analyzed, the initiating events or circumstances, the sequence of potentially hazardous events, any mitigating factors and characteristics, and the nature and frequency of possible detrimental effects of the identified hazards are examined. These criteria and measures should apply to risks to people, property and should include the values of estimation uncertainties [1].

Quantitative risk analysis allows you to evaluate and compare various hazards using common indicators. It is most effective:

- at the stage of design and placement of a chemically hazardous site (assessment of the compliance of operating production facilities and systems with the initial design solutions and subsequent modernization);
- when substantiating and optimizing organizational and technical measures of industrial safety (analysis of process hazards, periodic audit of industrial safety management, emergency action plan, checking the condition of the main and auxiliary systems and territories of the enterprise, and others);
- when clarifying and updating data on the main accident hazards, assessing the risk of major accidents at CHS with the same type of technical devices such as: main pipelines, separation equipment, chemical reactors, heat exchange equipment, storage tanks for hazardous chemicals (HC), pumps and other;
- when conducting a comprehensive assessment of the hazards of accidents for personnel working at an industrial enterprise, material property and the natural environment.

The first step in the quantitative risk analysis is the frequency analysis, which makes it possible to estimate the probability of each undesirable event identified in the hazard identification stage. The following three approaches are commonly used to estimate the frequency of occurring events: using existing statistics (history); obtaining the frequencies of occurring events based on analytical or simulation methods; using the opinions of experts in the field.

All of these techniques can be used individually or in combination. In the event that statistical data are not available or they do not meet the requirements, it is necessary to obtain the frequency of events by analyzing the system under study and its emergency conditions. Numerical data for relevant events, including data on equipment failure and human error, taken from operating experience or published official data, are used to determine an estimate of the frequency of undesirable events. The first two approaches are complementary; each of which has both strengths and weaknesses. Where possible, both approaches should be used, allowing them to be used for cross-checks. This approach serves to increase the degree of reliability of the results. In cases where these approaches cannot be used or are insufficient, it is recommended to involve the opinions of experts [1].

The analysis of works carried out by the authors in this direction [2, 3] made it possible to evaluate and form a database of the causes of accidents and accidents at enterprises with CHS by categories of elements of Process Safety Management (PSM). The percentage contribution to accidents by category is as follows: process safety information – 5.6%; process risk analysis – 16.2%; order of work – 16.8%; employee participation – 13.2%; occupational safety management training – 11.0%; training of contractors – 2.5%; pre-start safety check – 1.6%; mechanical integrity – 9.2%; firework permition – 7.0%; change process management – 8.2%; incident investigation/ accident investigation – 4.0%; emergency planning and emergency response – 2.7%; security compliance audits – 1.0%; trade secret protection – 0.8% [2, 3].

A more detailed analysis of the regulatory and technical documentation [4] allowed the research group to form a database segment containing the frequencies of emergency depressurization of typical equipment (pipelines, pumps, pressure vessels, tanks and isothermal storages, heat exchangers, automobile and railway tanks) used at hazardous chemical sites, operating in various technological modes, technical parameters, operating conditions. This information was taken into account by the authors to further determine the weight of the criterial parameters included in the clusters for assessing the industrial safety management system at an enterprise with a chemical organization.

The second step in quantitative risk analysis is the impact analysis. This stage provides for determining the results of the impact on the working personnel and the material base of an industrial enterprise in the case of an undesirable event (incident, accident). For safety risk calculations, consequence analysis is a determination of the number of personnel working at an industrial enterprise that may be exposed to hazards during an accident at a chemical waste disposal facility [1].

Unwanted events typically consist of situations such as the release of toxic materials, fires, explosions,

emission of particles from collapsing equipment, etc. Consequence models are required to predict the scale of accidents, catastrophes, and other phenomena. Knowledge of the mechanism of the process of releasing energy or material and the subsequent development of the situation occurring with them makes it possible to forecast the corresponding physical processes in advance.

Consequence analysis is used to assess the likely impact that an undesirable event will cause. Consequence analysis should:

- be based on selected undesirable events;
- describe any consequences resulting from undesired events;
- take into account the existing mitigation measures in the enterprise with CHS, along with all relevant conditions that affect the consequences;
- establish the criteria used to fully identify the consequences;
- consider and take into account both immediate consequences and those that may manifest themselves after a certain period of time, as well as the secondary effects that apply to adjacent equipment and systems.

Currently, there are several specialized databases containing information on industrial disasters, accidents and incidents that occurred in the chemical process industry [5].

According to the Organization for Economic Co-operation and Development (OECD) [6], the vast majority of accidents in the chemical process industry could have been avoided if the lessons learned and existing knowledge had been effectively applied. It is claimed that about 95% of the causes of accidents are known [7], but they occur or recur due to poor dissemination and use of information about past accidents [8, 9]. Knowledge is enough to prevent accidents, but the problem is how to use the lessons learned from accidents that have already occurred [10].

The methodological approach being developed by the research group is primarily aimed at assessing and analyzing the current situation at an industrial enterprise where CHSs are located, from the standpoint of preventing the occurrence (forecasting) and further development of an emergency, rather than analyzing the consequences of undesirable events.

When carrying out a quantitative assessment, the risk should be expressed in the most appropriate indicators (the third stage of quantitative analysis), which allow in the future to carry out a full-fledged analysis of the industrial safety system of the enterprise. Assess the absolute and relative risk of events associated with accidents at CHSs.

When conducting an analysis, it is necessary to establish whether the calculated risk assessment reflects the level of the overall risk or is only an integral part of it. When calculating the risk, it is necessary to take into account the likelihood that working personnel will be exposed to it.

The data used in calculating the levels of risk must correspond to a specific type of application (assessment of the level of operability of the industrial safety system of an enterprise with CHSs). Such data should, as far as possible, be based on the specific circumstances being analysed. If these are not available, general data that is specific and representative of the situation should be used, or credible expert judgment should be used.

Data should be collected and grouped in a format that allows easy retrieval of information for use in risk analysis. Data that no longer correspond to the current state of the industrial safety system of an enterprise with CHSs should be identified and excluded from the array of information used in further analysis, assessment of the absolute and relative risk of events associated with accidents, and in the development of appropriate measures and recommendations.

The work carried out by the authors in this area made it possible to proceed to an expert study and form the main clusters to determine the risk indicator of the risk of incidents and accidents: organizational; technical (equipment); human (staff); technological (design) taking into account the hazardous chemicals used in the technological process, as well as grouping in them a set of criterion parameters according to the corresponding specialization. When creating a cluster that describes the index of the vulnerability of the working personnel of an industrial enterprise from a chemically hazardous site, the authors considered measures and actions aimed at assessing the state of protection of personnel at workplaces and on the territory of the enterprise. The analysis of these clusters and the criterial parameters included in them will make it possible to evaluate and prevent the development of an emergency at enterprises with CHSs.

Generally, there are many uncertainties involved in risk assessment. An understanding of uncertainties and their causes is essential for the effective interpretation of risk values (fourth step of quantitative analysis). An analysis of the uncertainties associated with the use of the collected data, the methods applied and the models used to assess the expected risk of accidents at enterprises with CHSs plays an important and essential role. Uncertainty analysis involves the identification of all possible changes and inaccuracies in the results of the simulation, which are a consequence of the deviation of the parameters and assumptions used in the construction of the model. An area closely related to uncertainty analysis is sensitivity analysis. Sensitivity analysis involves determining changes in the response of the model to deviations of individual criteria parameters describing the model data.

The estimation of uncertainty in our case primarily consists of the transformation of the uncertainty of the choice from the set of values of the criterial parameters included in the model into the uncertainty of the final results in accordance with the constructed risk model. Requirements for the completeness and accuracy of the risk assessment should be formulated

as fully as possible. Where possible, all sources of uncertainty should be identified and eliminated. This applies both to the uncertainties of the collected initial data, that is, the most accurate formulation of the concepts and values of the criterion parameters (when conducting surveys at industrial enterprises), and to the uncertainties in the multifactor model (the accuracy of setting the specific weights of the criterion parameters and clusters). The criteria parameters and, accordingly, the clusters to which the analysis is most sensitive should be precisely defined.

In order to eliminate uncertainties at all stages of research on the development of a methodological approach to the analysis and assessment of the risk of accidents at CHSs of enterprises of the Republic of Kazakhstan, it is proposed to use a «feedback system». This system was used both at the stage of formation of primary initial data, the formation of final clusters in the areas of assessing the causes leading to accidents, and when creating final questionnaires for enterprises of the Republic of Kazakhstan containing chemically hazardous sites. This approach allows users to adjust and take into account the features of the technological processes of the production of CSOs of specific enterprises.

Conclusions

The problems associated with the wrong risk reduction strategy used in the chemical manufacturing industry to prevent accidents may be the main reason why accidents continue to occur worldwide and deserve further study. An analysis of their development shows that for many types of emergencies it is necessary to establish uniform criteria that reflect their nature and allow determining the level of emergency threats for enterprises with chemically hazardous sites.

The quantitative analysis made it possible to evaluate the completeness and reliability of the initial data, the adequacy and accuracy of the schemes used, the validity of the assumptions made and the dependence of the recommendations and conclusions on them. The researches carried out made it possible to identify priorities and types of hazards that should be considered in more detail.

The results of the research on quantitative analysis within the framework of this work allowed the research group to form the information basis of the developed methodological approach to the creation of multi-factor models and systems for assessing and managing risks based on a multi-criteria decision-making methodology based on the method of expert assessments and statistical analysis.

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Химиялық қауіпті объектілері бар өнеркәсіптік кәсіпорындардағы авариялар қаупін талдау мен бағалаудың әдістемелік тәсілін әзірлеу үшін сандық талдауды қолдану

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Аңдатпа. *Жұмыстың мақсаты – Қазақстан Республикасының химиялық қауіпті объектілері (ХҚО) бар кәсіпорындардағы жазатайым оқиғалардың тәуекелін талдау мен бағалаудың әдістемелік тәсілін әзірлеу үшін сандық талдауды қолдануды ұсыну. ХҚО бар кәсіпорынның қауіпсіздікті басқару жүйесін кешенді бағалау мақсатында сандық талдауды кезең-кезеңімен қолдану қарастырылған. Бұл ретте бағалау технологиялық өндірістік процестің ерекшеліктерін, авариялардың негізгі қауіптері туралы деректерді нақтылау мен жаңартуды, ХҚО бар кәсіпорындарда қолданылатын ұйымдастыру-техникалық шараларды негіздеу мен оңтайландыруды ескере отырып, нақты талданатын жағдайларға негізделеді. Жүргізілген зерттеулер кластерлерді қалыптастыруға және авариялар мен авариялар қаупінің индикаторларын және өнеркәсіптік кәсіпорынның жұмысшы персоналының химиялық қауіпті объектіден осалдығын сипаттайтын критерийлер жиынтығын әзірлеуге көшуге мүмкіндік берді.*

Кілт сөздер: *технологиялық қауіпсіздікті басқару жүйесі, сандық талдау, апат, оқиға, химиялық қауіпті объект, кластер, критериалды параметр, төтенше жағдайлар, салдарларды талдау, сезімталдықты талдау.*

Применение количественного анализа для разработки методологического подхода к анализу и оценке риска аварий на промышленных предприятиях с химически опасными объектами

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Аннотация. *Целью работы является представление использования количественного анализа для разработки методологического подхода к анализу и оценке риска аварий на предприятиях с химически опасными объектами (ХОО) Республики Казахстан. Рассмотрено поэтапное применение количественного анализа с целью комплексной оценки системы управления безопасностью предприятия с ХОО. При этом оценка производится, основываясь на конкретных анализируемых обстоятельствах, учитывающих особенности технологического производственного процесса, уточнении и актуализации данных об основных опасностях аварий, обосновании и оптимизации организационных и технических мер, применяемых на предприятиях с ХОО. Проведённые исследования позволили сформировать кластеры и перейти к разработке множеств критериальных параметров, описывающих показатели опасности риска аварий и несчастных случаев и уязвимости работающего персонала промышленного предприятия от химически опасного объекта.*

Ключевые слова: *система управления безопасностью процесса, количественный анализ, авария, инцидент, химически опасный объект, кластер, критериальный параметр, чрезвычайные ситуации, анализ последствий, анализ чувствительности.*

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