Consideration of external natural impacts in the design of hazardous production facilities

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Abstract. In the contemporary society the need for assurance of technological and environmental safety of production facilities (PF), including hazardous ones, is dictated by technological development of the economy. This fact presupposes that the criteria of potential natural factors (geological, hydrological, meteorological) impact should be clarified during the design process. Insignificant number of available scientific generalizations of external factors impact on PF does not allow for making an initial protectability assessment of production complexes and adjacent areas. This research is aimed at developing a methodical approach to considering natural effects (including the extreme impacts) in assurance of PF's technological protection and environmental safety in the areas adjacent to PF. The use of threshold probability of beyond design basis accident as the main probabilistic criterion is substantiated for decision making on whether to consider the external natural factors impact on PF or not. Along with it, is shown that the specified levels of probability of various natural factors occurrence should be revised upwards with account of detailed computations of accident scenarios at a PF. It is noted that risk management of PF exposure to external natural impacts should stipulate that monitoring of such factors should be arranged and carried out.

1 Introduction

Due to the intensive technological development of the economy in contemporary society, the issues of environmental and technological safety assurance of production facilities (PF), including hazardous ones, have gained special relevance over the last years. Hazardous production facilities include nuclear facilities, hydraulic structures (HS), chemical enterprises, mining enterprises, solid domestic waste landfills, tailings dams, ash dumps, etc.

In many cases, external natural factors of geological, hydrological and meteorological origin turn to be hazard sources for a PF. As a result of accidents and incidents at a PF, a threat to human life and health, environmental degradation and economic losses may arise.

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In many cases, even during normal operation of hazardous PFs, adverse natural conditions may cause damage to man and the environment.

The need for comprehensive protection of the environment from potential extreme and adverse natural situations, in compliance with the Concept of sustainable development, envisages a detailed study of the natural conditions in the PF siting areas [1]. At that, emphasis should be placed not only on the study of hazardous and extremely hazardous natural phenomena and processes, but also on the ongoing ones, like e.g. current weather conditions.

Development of hazardous situations at PFs is closely linked with the main and auxiliary technological processes, construction systems and a set of protective engineering actions [1]. It is the natural factors that in certain conditions determine a list of required actions to ensure PF's technological protection and environmental safety of their siting areas. In this link a fan effect may be observed when an individual system or structure is exposed to a set of factors, as a result of which the entire system can become inoperable and the environment can be impaired intolerably. At that, special hazards are imposed by nuclear facilities, hydraulic structures, chemical enterprises, etc. [2, 3]. Examples include the notorious events at the Fukushima nuclear power plant [4], dam breaks [5], etc.

Lack of a well-defined classification of external impact factors and their ranking, unreliable consideration of risks and probabilities of impacts does not allow to make a full-scope initial evaluation of the protection of industrial complexes and adjacent areas. Therefore, the aim of this research is to develop a methodical approach to considering natural impacts (including the extreme effects) in assuring PF's technological protection and, consequently and indirectly, environmental safety in the areas adjacent to PF.

2 External natural impacts

External natural impacts that significantly affect the PF's safety, include the following:

- geological and engineering-geological processes and phenomena –seismotectonic ruptured displacements, seismic dislocations, seismotectonic uplift, subsidence of crustal blocks, modern differentiated crustal movements, tectonic creep, residual seismic crustal deformation, earthquakes of any genesis, volcanic eruption, mud volcanoes, landslide, landslip, mudflow, avalanche, erosion of river banks and beds, karst occurrences, permafrost-geological processes, suffusion, etc.;
- hydrological processes and phenomena – flooding, tsunami, ice phenomena on water ways (jams, ice dams), coastal zone of seas (downsurge, upsurge, storm phenomenon), seiches, tidal surges and ebbs, extreme water levels in water ways, extreme river flow;
- meteorological processes and phenomena – tornado, tropical cyclone, extreme wind, extreme air temperature, extreme precipitation, extreme snowfall and snow pack, avalanches, glazed ice, lightning strike, etc.

It is envisaged that the impacts listed above should be taken into account to develop safety provisions for PFs at all stages of their life cycle, and consequently to minimize the risks of impact of the above factors and ensure environmental safety. The environmental data, and in particular the engineering surveys documents, are used as input data for developing engineering protection of the environment. It should be noted that in order to achieve these objectives, it is necessary to set up monitoring of the state of environmental components in the zones of technogenic impact of PFs.

3 Probabilistic safety criteria

When making decision on whether to consider or refuse to take into account the impact of one or another external environmental factor on a PF, the probability (likelihood) of this factor's effect on generating adverse consequences for both the PF and the environment is normally taken as a guidance [2, 3, 6, 7]. Such a probabilistic approach is applicable for nuclear facilities, to the greatest extent. Thus, in Russia and in other countries as well, the safety requirements for nuclear facilities are set forth based on the condition that the probability (frequency) of a beyond design basis accident with a peak emergency release (discharge) to the environment $P_G = 10^{-7}$ 1/year is inadmissible. This value is the main criterion of nuclear facilities' protection against external impacts. In a similar way, for other, less hazardous PFs the threshold probability P_G may be higher. Thus, for hydraulic structures, depending on the hazard category thereof, the normative threshold probability P_G varies from 5×10^{-5} to 5×10^{-3} 1/year. It is obvious that the higher the threshold probability of P_G , the weaker the external impact.

According to [3], the design bases of nuclear facilities include the design values of external impacts of natural genesis; the design values are calculated for probability level P_0 of occurrence thereof, which equals 10^{-4} 1/year. For hydraulic structures the probability level P_0 is taken from 10^{-4} to 10^{-2} 1/year, depending on the hazard category. Accident probability at a PF caused by impact of one or another natural factor of natural origin is as follows:

$$P = P_0 \times P_A,$$

where P_A is the probability of a design basis accident that leads to an extreme situation in the natural environment when a natural factor with design basis parameters occurs. With account of the above main criterion for nuclear facilities, when $P_A > 10^{-3}$ the impact of this factor will lead to a probable beyond design basis accident that accedes the main safety criterion P_G . For hydraulic structures, depending on the category thereof, a beyond design basis accident is anticipated at the P_A probability values varying from 0.05 to 0.1. In view of this fact, consideration or refusal to consider one or another natural factor should not proceed from the condition of P_0 threshold probability implementation envisaged in [3, 8] but from the following condition:

$$P_0 \times P_A > P_G \text{ (to be considered)}$$

or

$$P_0 \times P_A < P_G \text{ (refused to be considered)}$$

of the given factor when designing the PF's engineering protection.

With account of the above circumstances, it should be emphasized that when designing a PF, beyond-design-basis accident probability minimization is of great importance; and it is done by means of developing engineering safety features against the impact of external natural factors. At that, the normative levels of extreme phenomena occurrence P_0 set forth in [3, 8] could be revised upwards with account of detailed computations of accident scenarios at the PF. It is noted that risk management of PF exposure to external natural impacts should stipulate that monitoring of such factors should be arranged and carried out. The revision of probability levels of such impacts is also justified by the fact that many kinds of external impacts are observed rarely and it is difficult in many cases to obtain reliable statistical data on their occurrence [2]. Therefore, collection and accumulation of data on hazardous natural processes and phenomena is of great significance.

It is stated in [7] that potential hazard of certain natural factors impact may be overestimated in many cases and it can result in excessive financial costs for the PF's

engineering safety actions. On the other hand, clarification of probabilistic criteria and reliable assessment of the PF's destruction probability can increase the safety level thereof.

Figure 1 shows a block diagram of decision-making process for consideration of a single external natural factor and assurance of the PF and the environment safety against its impact.

Fig. 1. Decision-making diagram of considering the external natural factor and ensuring safety of the PF.

In order to manage natural factor risks and take managerial decisions on prevention and mitigation of emergency situations caused by external natural factor impact, it is necessary to organize and carry out monitoring of these factors. Such monitoring should be performed at the key stages of the PF's life time – construction, operation and decommissioning (dismantling).

4 Conclusions

- In the contemporary society the need for assurance of technological and environmental safety of production facilities (PF), including hazardous ones, is dictated by technological development of the economy. This fact presupposes that the criteria of potential natural factors (geological, hydrological, meteorological) impact should be clarified during the design of such facilities.

- Threshold probability of beyond-design-basis accident caused by this factor should be used as the main probabilistic safety criterion for decision making on whether to consider the impact of one or another external natural factor on the PF or not. In its turn, the threshold probability value is determined by the PF's hazard category.

- It is shown that in order to prevent accidents at PFs, the probability levels of occurrence of various natural impacts established in regulatory and technical codes and standards, it is reasonable to revise the probability levels upwards with account of detailed computations of accident scenarios at a PF. Revision of probability levels of such impacts is also justified by the fact that many kinds of external natural impacts are observed rarely and in many cases it is difficult to obtain reliable statistical data on their occurrence.

- It is noted that clarification of probabilistic criteria and reliable probabilistic assessment of PF destruction can increase the PF's safety level.
- Management of natural factor risks and taking managerial decisions on prevention and mitigation of emergency situations caused by external natural factor impact stipulate that monitoring of the said factors should be set up and carried out.

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