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FAILURE AND ACCIDENT RISKS OF TECHNICAL SYSTEMS IN SIBERIA AND THE ARCTIC

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Abstract

In the paper is presented the complex analysis of object technosphere safety is particular of current interest for Siberian and Artic of the Russian Federation where a wide range of hazards are. The uniqueness of territory (various natural-climatic and geological conditions, huge actual reserves at biogenic and mineral resources, significant industrial protentional with complex transport infrastructure and etc.) causes a large number of hazards. There are some examples of analyses of results technical diagnostic for technosphere objects including fabricated constructions, mainland pipeline, etc. and their using for estimating the reliability and accidents risks as well.

Keywords: reliability, technogenic safety, failures

I. Introduction

The development of technosphere influences quality of life raise on the one hand, one the other hand – new hazards appear, including accident and emergencies with fatality and severe damage (scientific-technical dilemma of progress). In these terms the safety of every industrial or urban territories which should be considered as socio-naturel-technogenic system (S-N-T system) is one of them most basic indicates for sustainable economic development. Firstly, there are two tasks:

1. Monitoring, diagnostics and expertise of potentially hazardous objects providing safety and function of main production facilities.
2. Assessment of reliability and technogenic risk is on the basis of statistical data on hazardous events and safety theory which are based on the results of model off-nominal conditions and on the conception non-zero accident risk..

The complex research of object technosphere safety is particular of current interest for Siberian and Artic of the Russian Federation where a wide range of hazards are. The uniqueness of territory (various natural-climatic and geological conditions, huge actual reserves at biogenic and mineral resources, significant industrial protentional with complex transport infrastructure and etc.) causes a large number of hazards. Development of natural resources and territories' urbanization effect the increase anthropogenic impact on unique natural complex and decline of common ecologies condition area [1].

Nowadays the main anthropogenic impact for the north territories is going to be contacted with oil and gas complex (OCG) development in Krasnoyarsk region, Tyumen region and Yamalo-Nenets Autonomous Okrug. OCG impact on the environment will have significant sizes and involve all natural constituent (atmosphere, soil, forest, water objects, animal and land scape). The building of gas and oil transmission pipelines with oil transfer (OTF) and compressor facilities (CF) has been planned for organizing oil and gas transportation. Planning emissions from one OTF are equal to 348 t/y and the emissions from one CF – 1131 t/y. Emergency leak of oil products while loss of containment and equipment destruction should be considered strong sources of danger. The failure rate of main OGC equipment figures up to $1{,}2\cdot10^{-5}$ – $3{,}5\cdot10^{-3}$ year-1. The loss of containment rate ranges within $2{,}9\cdot10^{-6}$– $5{,}8\cdot10^{-5}$ year^{-1}, flowlines - $7{,}5\cdot10^{-5}$ – $2{,}5\cdot10^{-4}$ year^{-1}, transmission pipelines - $6{,}9\cdot10^{-5}$ – $4{,}3\cdot10^{-4}$ year^{-1}. Due to complex natural-climatic condition of Siberia and Extreme North OGC objects have to have high levels of safety which provide conservation for unique ecological system. So systematic monitoring and mathematical simulation anthropogenic impact on the environment are required [1].

II. Cause-and-effect complex of failures.

Analysis and generalization cause-and-effect complex failures of technical system are constituent part pf accident risk assessment [2]. The cause-and-effect complex is formed by main reasons and actual loads which lid to different kinds of damage (fig. 1). The failure and accident are realization and combination several reasons and different events: human factors, changes in operating conditions, weather conditions, technological violations, etc.

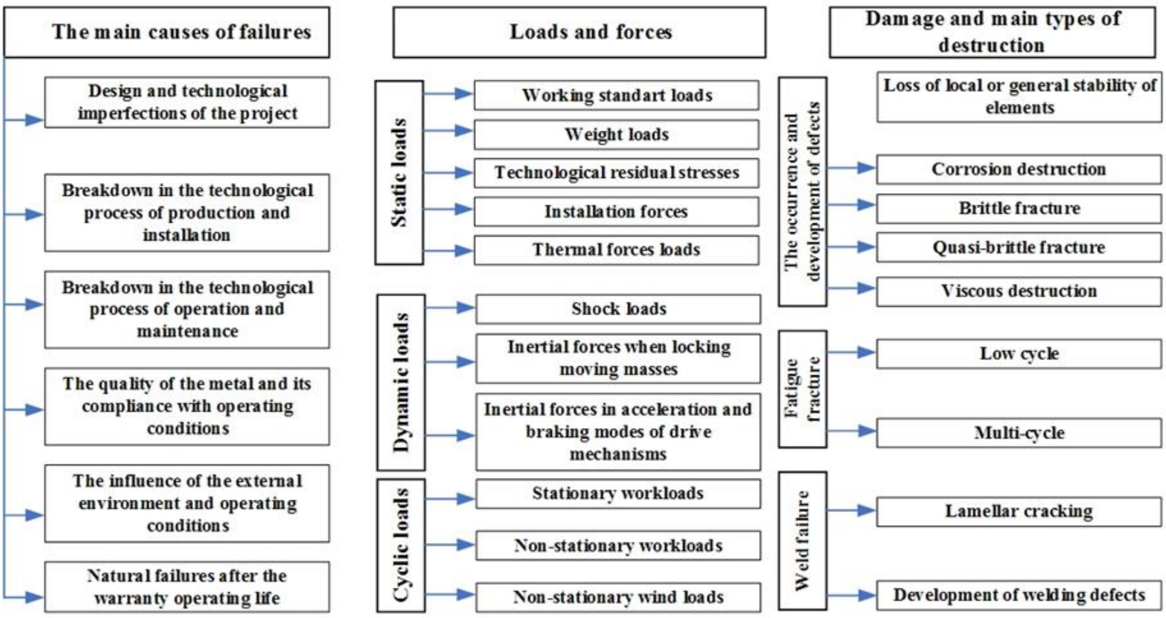


Figure 1: *Cause-and-effect complex of failures of technical systems and engineering structures [2].*

Accidents and disasters must be considered as probable events. As a rule similar accidents and disasters can be caused by different reasons. In figure 2 there is a logical schema of accident and disasters. It shows different accident and disasters (the main event F) occurring in various failures technical system (the event E) and trigger factors (the event H). The event E are formed during engineering process producing or operation technical systems on base of logical schema "AND", "OR", "m from n". Trigger factors are formed installation inspection or operation due to systematic develop events ("domino" effect) or they appear as a result of events groups realization which are made from the presented logical schema.

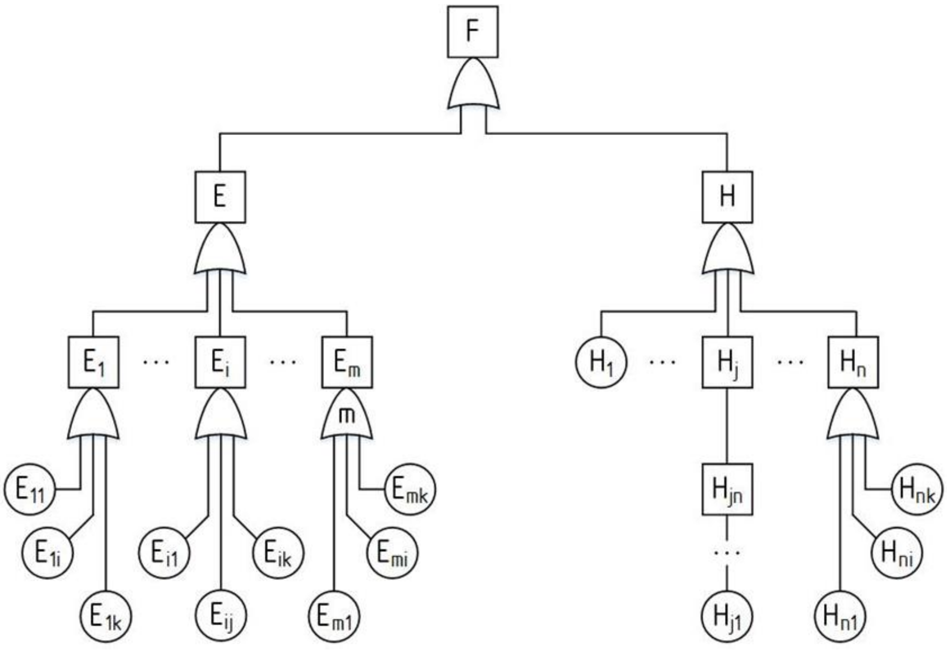


Figure 2: *Logical accidents and catastrophes scheme of technical systems*

On bases of logical schema probability of the event can be calculated which is conditional probability:

$$P(F) = P(H/E) = \frac{P(H \cap E)}{P(E)} \quad (1)$$

If *P(E)*>0, *P(H)*>0 probability of the accident will be *P(F)*>0. So creatures of absolutely safety technical system with non-zero risk of accidents and disasters is impossible. This conclusion is the basis of non-zero risk conception.

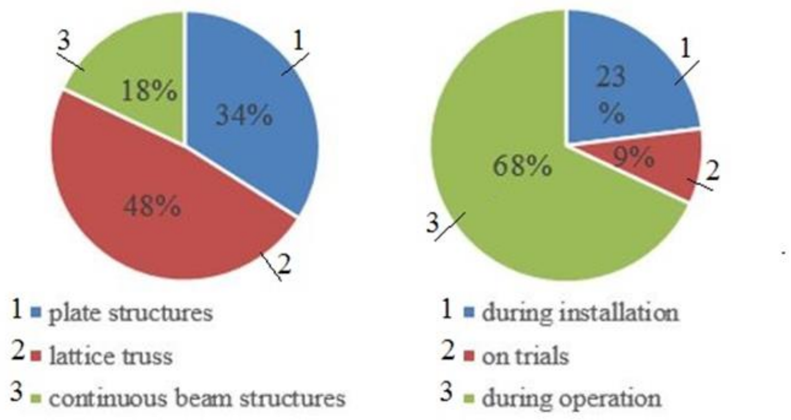
III. Failure and reliability statistics for technical systems.

Cause-and-effect complex of links forming level operation reliability of constructions are identified by power actions connecting with burden, causes and kinds of failures.

The statistic data are presented below. These data of accident and failures for technical system are given for wide use in Siberia and Arctic: engineering structures, currying-and-lifting and mining machines, objects of power and oil-gas industries.

Engineering metal structures. Due to the analysis of 350 typical situations of steel structures destruction in West and East Siberia areas [2] (fig. 3) the statistical data about engineering metal structure failures were given and the main reasons including factory defects structures (production stage) and mistakes on design stage were discovered (table 1). General percent of failures connected with low level of planning and production quality rans up to 60%.

The influence separate factors on forming failures structures possibility is viewed [1-4]. In figure 4 dependents of structures destruction possibility on relationship between strains acting on the devastating moment σ_d and calculating σ_c are showed. For engineering constructions (beams, overpasses, trusses) calculated devastated strain range from 0,2 to 1,0 ($\sigma_c \approx 0,8$ under 50% probability). Calculated strains are about 1,2 σ_c for tanks. However, on the other hand approximately 20% tanks destruction happened without external action but from fixed load efforts. Low levels strains are basic for brittle structural failures. The analyze of curve failures (temperature distribution (fig. 5)) shows the rang of temperature failures for majority engineering structures is from -50 to -5 °C.



a *b*

Figure 3: *The frequency of destruction by types of structure (a) and fracture time (b)*

Table 1: *The main failure reasons of engineering metal structures*

Failure reason	Frequency, %
Mistakes made in projects	27,0
Steel grade mismatch with loading and temperature conditions	11,0
Defects of prefabricated structures	30,0
Breakdown during operation of computational model constructions and exceeding of permissible loads	14,0
Imperfection of existing norms and rules of design and manufacture of metal structures	6,0
A set of other reasons	12,0

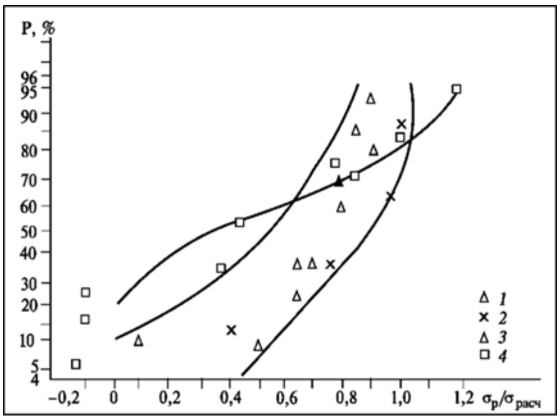


Figure 4: *The distribution of the destruction probability of building structures from the level of stress (1 - beams; 2 - flyovers; 3 - trusses; 4 - tanks)*

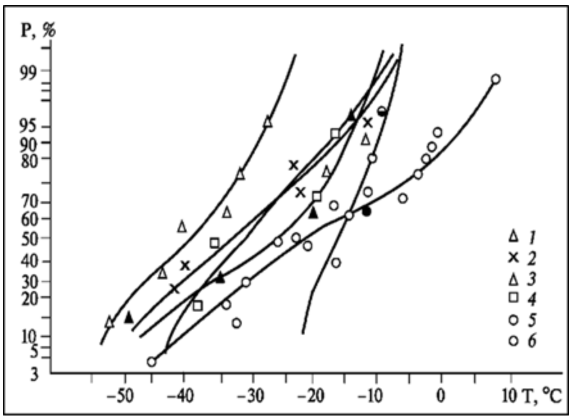


Figure 5: *The influence of operating temperature on the accumulated destruction frequency of various building structures (1 - power transmission towers; 2 - trusses; 3 - beams; 4 - flyovers; 5 - tanks; 6 - bridges)*

Realization of any failures is consequence of different influence power (fig. 1) and specified factors combination. These circumstances are complicated by design errors, technology disbalances during installation and deviations from the operating rules. The data analysis has led to per cent rating for main kinds of engineering metal structures destructions (fig. 6) according to fig. 1.

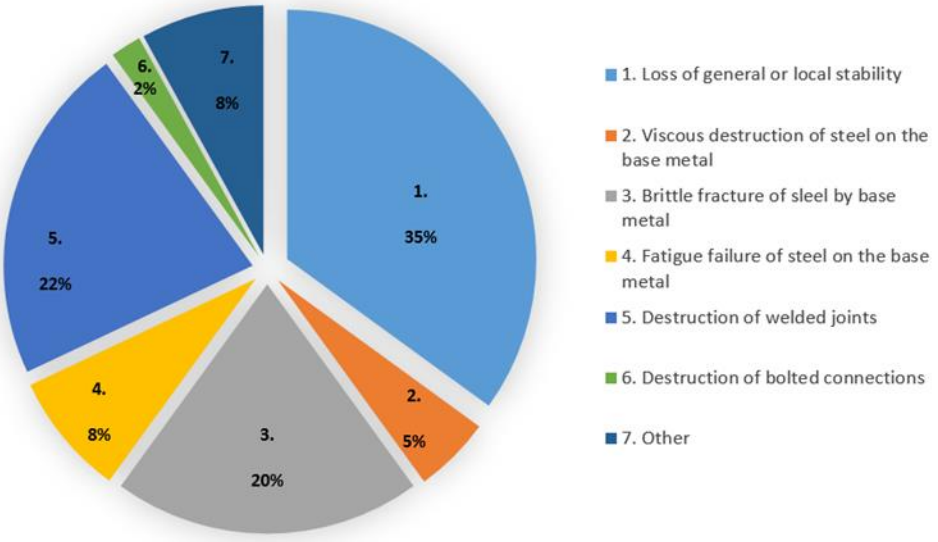


Figure 6: *Type and frequency of failures*

Carrying and lifting machines. Crane structures are one of the most common types of industrial equipment. Specificity failures and accidents depends significantly on crane type (overhead traveling, cross gantry and tower cranes) and carrying power. The real practice crane use is marked by numerous destructions of bearing elements. It is connected with fatigue cracks incurrence in structure elements after 15-20 years operation.

The main failures causes are [5, 6]:

- mismatch chemical compound and metal mechanical characteristic to technical requirement;
- fatigue fractures;
- long term operation without diagnosis;
- low operation temperatures;
- strains structures;
- technological defects in welded seams.

As an example of characteristic general reliability for crane construction the results of operation observation of overhead traveling crane failures (period of 7 years) are examined table 2.

Table 2: *The main indicators of the overhead traveling crane reliability (Q=125 tnf)*

Indicator	Mechanical equipment	Electrical equipment	The crane as a whole
The number of failures	104	160	264
Average time to failure, full day	26,90	16,59	10,36
Mean square deviation of time between failures, full day	24,87	17,96	9,66
Average recovery time, h	1,41	0,65	0,94

As table 2 shows the number of mechanical equipment failures is equal 40% from total number. The average time between failures is mechanical equipment higher than the same electrical facilities measure in 1,62 times. Mechanical equipment is more reliability in terms of faultless but from the point of repairability it worse than electrical facilities. An average measure and failure interval vary less from root-mean-square deviation it allows to accept hypothesis of exponential distribution. In figure 7 reliability crane functions and its main subsystems are shows. The exponential distribution of failure interval proves simple character of failure flow which is typical for multiple system.

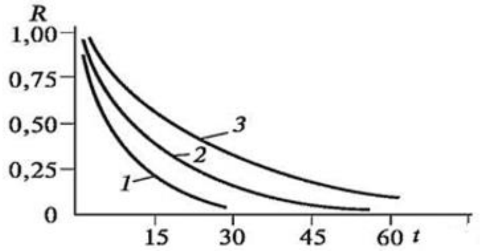


Figure 7: *Reliability functions for overhead cranes (1), electrical equipment (2), and mechanical equipment (3)*

Mining equipment. It's presented by mining and rotary excavators, dragline and dump truck of large capacity. Studying of excavators accidents in mining companies [1, 6-8] has allowed to establish than technological and operation defects, conflict between steel parameters and operation conditions play the main role in failure reasons. Wrong structures solutions and human factors make a considerable contribution to forming accident.

Climate conditions of operation are distinguished from main factors leading to excavator failures. The low steel cold resistance is determine factor in failure forming of excavator metal structures of low temperatures. The analysis of node point and metal structures failures (temperature dependence) shows that reduction of temperature from 250 to 230 K results in failures increase twice minimum and at temperature low 250 K it races up (fig.8). According to exponential law of failure interval distribution the functions of excavator reliability and node points are built (fig.9).

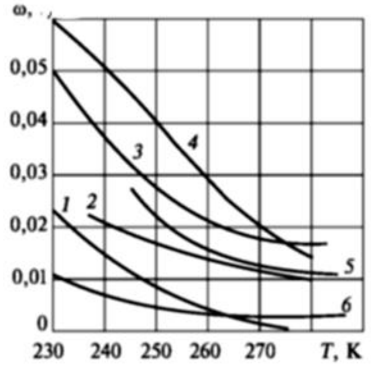


Figure 8: *Temperature dependence of the failure flow parameter for excavator metalwork elements.*
1 – the beam of a handle of an crawler-mounted excavator (CME)-4,6; *2* – two-legged CME stand -12,5; *3* – the CME boom -4,6;
4 – the CME bucket -4,6; *5* – the beam of a handle of an CME -12,5; *6* – the CME boom -20

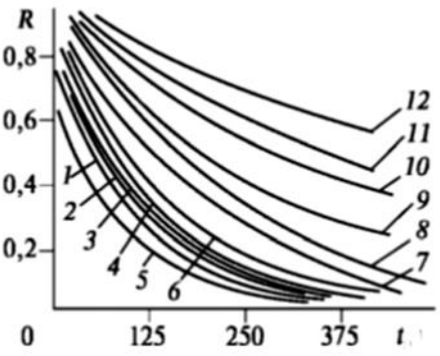


Figure 9: *The reliability function excavators.*
1 – the rotary excavator (RE)-2500; *2* – the CME -12,5; *3* – the RE -1250; *4* – the CME -4U; *5* – the rail-stepping rotary mining excavator -5000; 6 – the CME -8I; *7* – the walking excavator -10/70A; *8* – the CME -6,3; *9* – the mechanical system of CME -6,3 (winter); *10* the mechanical system of CME -6,3 (summer); *11* – the mechanical system of ЭКГ-8I (winter); *12* – the mechanical system of CME -8I (summer)

Among other failure factors there are mining technological and organizational ones which have specificity of statistical methods unpredictability. Due to power machines increasing in cold climate areas probability of occurrence of brittle destruction metal structures enhances and down time from unscheduled repair grows by on 30-40%. The distribution of mechanical part truck failures (capacity until 75 tnf) is presented in fig.10 [9]. Failures of truck technical systems make contribution to forming low parameters of reliability. Percentage of uptime for machines doesn't go beyond 0,6 [8, 9].

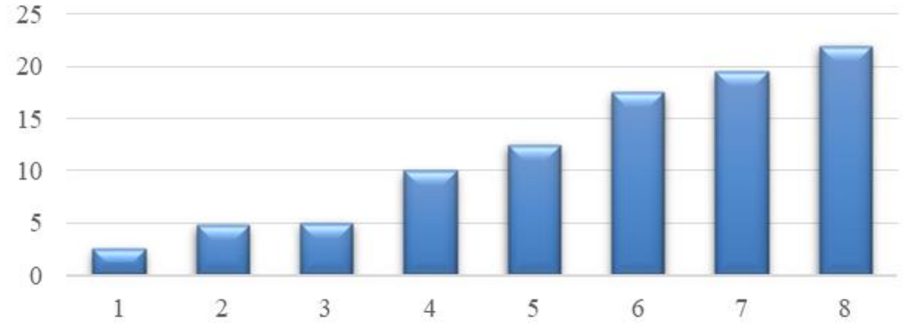


Figure 10: *Distribution of failures of the mechanical part of dump trucks BelAZ-75211, -75213: 1-nave; 2-rim; 3-rear axle; 4-frame; 5-platform; 6-front girder; 7-suspension; 8- jet rod*

Thermal power equipment. Period of operation for main part of thermal power technological equipment (boiler systems, steam generators, hot water and steam pipelines, pressure vessels and etc) surpasses significantly design service and economic life [10-12]. The same problem is found in the EU and the USA. The analysis of consumption level of production facilities energy structures in Siberia shows that machine and equipment consumption reaches 63…72%, transfer mechanism – 57…65%. The rake of boiler faults in power generating unit of Russian CHP stations is 30,2…41,8%, in the USA – 42,5…64,2% [10, 11].The specific fault Russian boiler changes from 1,08 to 1,82 failures a year (the number of boiler faults, which crashes power-generating unit). The same numbers for the USA boiler are from 1,8 to 6,89 failures a year. The mass survey for heat-power engineering objects of technical condition shows significant number of defect boiler system elements (the data of Kuznetsk district State Mining and Safety Organization RF) (fig. 11) [12].

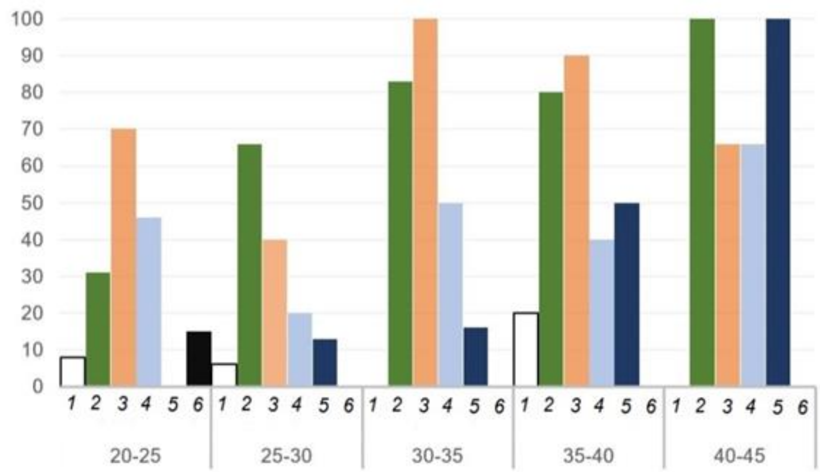


Figure 11: *Distribution of defects in boilers depending on the service life. 1-repair welding defects; 2-corrosion ulcers; 3-deposits; 4-thinning of the drum wall below the design value; 5-change in mechanical characteristics; 6-rolling defects*

Histograms and density functions of boiler life length system in power station are shown in figure 12. The boiler system of CHP-1, which have been in operation for more than 40 years and have fully used up the park resource have the most significant level of life lengths.

When analyzing of life lengths for CHP pipeline system using up of designed operation is the main reason. This conclusion is confirmed the data fig. 13 which shows histograms and density function of life length for pipelines CHP. The life length statistical analysis shows that the most acceptable the density function model is normal probability law.

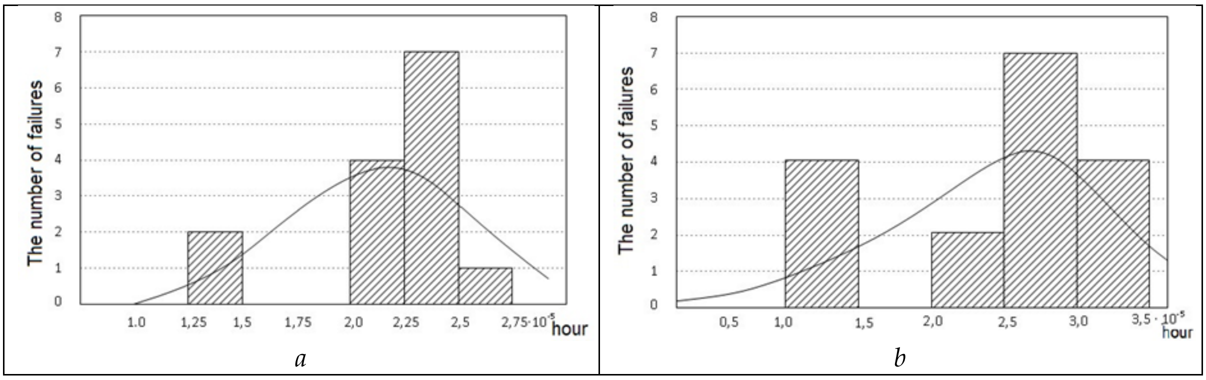


Figure 12: *Histograms and distribution density functions of the time between failures for the boiler plants of regional power station (a) and CHP-1 (b)*

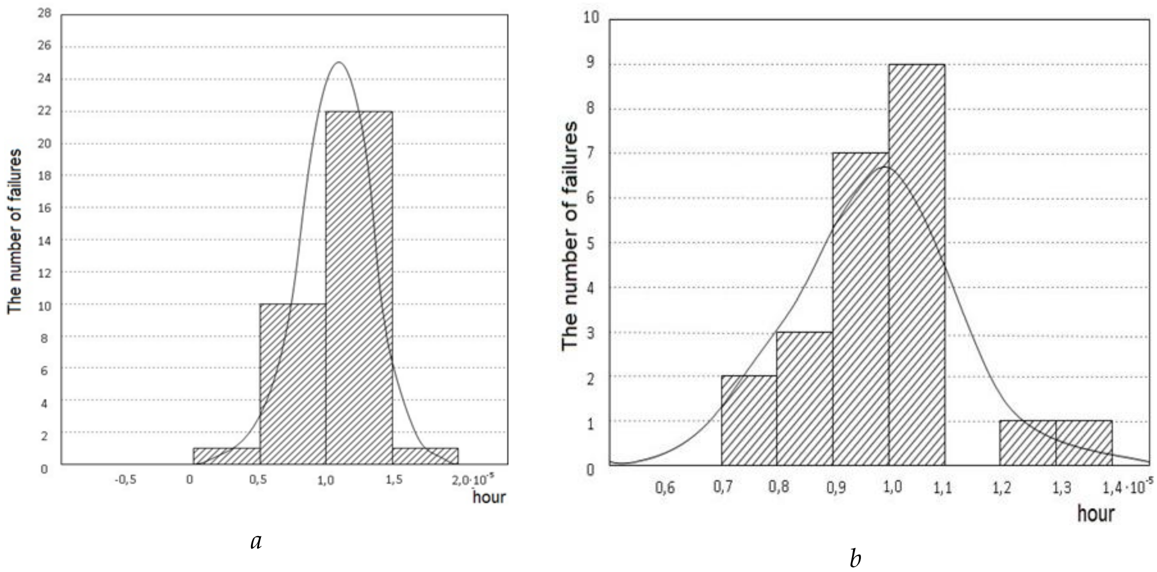


Figure 13: *Histograms and distribution density functions for the CHP-1 (a) and CHP-2 (b) pipelines*

General number of pressure vessel in Russian power station and substation is above 150 thousand units. The most dangerous in terms of accidents consequences welded connection faults is the data in table 3. The quantity of seams developing during the operation is 26,2 % from the all defects in basic part welding process. The bigger number of seams notes in high-pressure deaerators (70,6%) and heaters (15%).

In all kinds of pressure vessel undercutting is the most dangerous types of welding defect (10...25 %).

The discovered defects of pressure vessels predetermine raise demands to inspection of technical conditions objects in operation process and dictates necessity of strain-stress state pressure vessel analysis in local areas and the usage of probability methods for crack resistance calculation.

Oil-storage tanks. Destruction of tanks filled petroleum products are often followed by explosions and occurrence fires environmental pollution. A damage can be significantly higher than estimated construction cost of oil tank. The results distribution frequency of failure cases analysis by kind of main reasons show [1, 4, 13, 14] that brittle destruction has dominated quantity accident position (table 4).

Table 3: *The distribution of injuries according to the types of welded joints on the vessel*

Type of damage	Selections by vessel designation								
	HPH	HPL	Boilers	Deaerators	Receivers	PPR	Fuel oil heaters	Sulfuric acid tanks	All
Undercuts	22	10	19	20	10	8	3	-	92
Pores	6	7	10	12	-	1	1	4	45
Cracks	16	3	-	77	8	1	-	-	105
Sinks	14	4	1	4	10	1	-	1	35
Fusion	6	3	11	16	6	1	-	-	43
The offset edges	2	-	1	3	1	-	-	-	7
Low - quality welding	12	14	16	28	12	-	7	3	91
Cavity	2	-	-	-	-	-	-	-	2
Total	80	41	48	160	47	20	12	8	416

**HPH, HPL – high and low pressure heaters*
**PPR – petroleum product reservoirs*

Brittle destructions are result of following factors influence:

a). construction elements availability promoting strain concentration;

b). low quality of metal with nonnormality in chemical composition, mechanical features and resistance to cold;

c). local loss of metal ductility (riveting from striking, embrittlement, thermal influence while cutting and welding and etc.);

g). welding defects are stress raisers.

Defects of geometrical shape are secondary among possible accident reasons. However, they are dangerous in terms of brittle destruction because of stress concentration increase in local areas tanks as well as welding concentrators and low quality of steel.

Table 4: *Distribution of PPR failures by major causes and brittle failures*

Main reasons	**Number**
Brittle destruction	41
Explosion and fire	8
Vacuum	5
Corrosive wear	2
Hurricane	1
Drawdown of base	1
Other	7
Total	65

Causes of brittle destruction	**Number**
Design defects	9
Low quality metal	13
Local loss of plasticity	3
Welding defects	16
Total	41

IV. Conclusion

Failures, destruction, accidents are basic to any technical system and there are inevitable at any level of technique and technology development. While designing and creating complex technical system is impossible to force all external factor combinations in operation and take in to account all connection and cooperation between system elements. Technical system in process of operation inevitably attains some extra parameters and possible conditions which don't meet design. This is phenomena of evolutionary unexpectedness of accident initiation in complex technical object [4, 6].

Destruction, accidents and hazards of technical system appear to be one of the most informative sources in researching their real parameters. Accidental situation analysis is the most effective approach to control approximation of calculation and design methods in particular acceptable hypothesis and calculation models.

Therefore, accidental situation researchers of technical system constructions are the most significant stage for analysis and characterization as technosphere object. This requires more advanced approaches to studying and modelling of abnormal operation conditions within the concept of "non-zero accident risk".

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