2 Technogenic Emergencies: Can They Be Reliably Predicted?

The current level of science, technology, and production places individual countries and mankind in general at risk. Modern society becomes more and more concerned with technogenic safety. Having concentrated in a locational sense tremendous amounts of different kinds of energy, hazardous substances and materials, present-day industry has become a constant source of significant risks associated with mass loss of life and environmental problems during emergencies such as incidents, accidents, and disasters. Although mankind cannot develop without new technologies, their increasing use does not reduce potential risks, but to the contrary often creates new threats and risks. The use of increasingly sophisticated and energy-consuming equipment inevitably results in incidents if not handled properly.

It was believed earlier that technogenic emergencies were contingent and therefore were blamed on incidents, unfavorable circumstances, human error, etc. Now a somewhat different approach toward dangers related to human activities is evolving. It has been recognized that many of them are quite predictable and can be modeled and prevented to the fullest extent possible using appropriate preventive measures. The existing methodology and practice of ensuring reliability and safety of sophisticated man–machine systems can often solve these tasks successfully.

According to estimates, about 10–15% of technogenic disasters have measurable physical harbingers that can be used for forecasting such events and preventing their adverse consequences. The majority of such harbingers can be detected using ground-based or aerial means. However, in a number of cases involving extended engineering systems (such as trunk oil and gas pipelines, railroads, sea fleets, mining industries, hydroelectric stations, nuclear power plants, etc.), these tasks can be solved only by space monitoring systems. Moreover, it is often impossible to ensure compliance with safety requirements and subsequent safe operation without space monitoring data that are used when designing complex engineering systems or in the location of seismically and hydrologically safe places for their construction, and exercising construction supervision.

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Each technogenic disaster is unique in its own way. However, practically all of them are associated with failures of complex organizational and engineering systems, i.e., systems that involve during all cycles of their operation not only equipment but also people, whose faultless actions are critical to the reliability and efficiency of its work. According to Lee Davis, the author of "Man-Made Catastrophes," the so-called "human factor" that is to be blamed for up to 90% of technogenic emergencies boils down almost entirely to three circumstances: "stupidity, neglect, and greed." This may prompt a more positive conclusion: the above-mentioned reasons can be dealt with using preventive measures at all stages of an engineering system's life cycle, as cutting-edge industries do in developed countries. The authors of another work, "Man-Made Disaster," Barry Turner and Nick Pidgeon, take a broader look at the problem: although a technogenic disaster can happen virtually everywhere and there is no "absolute tool" that can avert it, there are a number of factors that can help "delay" it and minimize its consequences. The authors believe that these are mainly a high level of education and a pro-active civil position of local society. The more responsible and professional the residents of a certain country are in performing their obligations to society and the better society oversees them, the lower the probability of a technogenic disaster. The training of personnel in governmental agencies and private companies to act in emergencies is also vital.

Nevertheless, we have what we have: despite achievements in the development of automated and remote control technologies, and technical personnel training, the number of technogenic emergencies grows every year, challenging natural disasters in terms of destructive effects.

2.1 Technogenic Disasters in the Modern World: Classification, Facts, Consequences, and Tendencies

For decades, the well-known and influential Center for Research on the Epidemiology of Disasters (CRED) has been keeping a database of natural and technogenic disasters on the planet. According to the center's criteria, an emergency is a disaster if at least one of the following four events has occurred: more than 10 people have died, more than 100 people have been injured, and local authorities have declared a state of emergency or requested international assistance. A technogenic disaster is a type of disaster that is caused by a failure of engineering systems resulting in an accident at an industrial facility or on transport, which as a rule is accompanied by mass casualties among the population and an environmental disaster, and poses an immediate threat to public and national security. It is considered an emergency with all the ensuing social, legal, and environmental consequences.

One of the classification options for technogenic disasters (Fig. 2.1) divides them into three main types: "industrial" (radiation and chemical contamination, explosions, destruction caused by other factors), "transport" (air, sea, and railroad accidents, etc.), and "others" (all other disasters). By origin, technogenic disasters can be caused by: unintentional, erroneous actions of the maintenance personnel whose incorrect

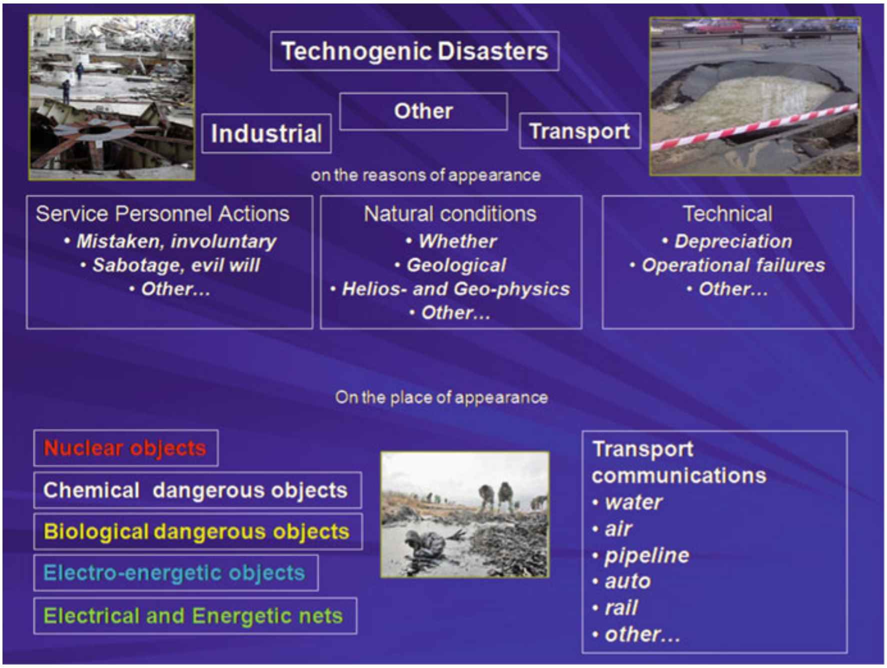


Fig. 2.1 One of the classifications of technogenic disasters

actions due to lack of attention or poor training provoked an accident (for example, the Chernobyl nuclear catastrophe), intentional actions of the maintenance personnel with evil intent or as sabotage; tectonic, natural, or weather conditions; wear and tear of equipment, or other unforeseen and undesirable consequences of standard operation of complex organizational and engineering systems (the accident at the chemical plant Union Carbide in Bhopal, India).

By the place of occurrence, accidents are divided into those at nuclear facilities of engineering and research centers and nuclear power plants (with destruction of production premises and radioactive contamination of the surrounding area); at hazardous chemical facilities (with release, spill, or leak of toxic substances); at research institutes (enterprises) that design, make, process, and transport bacterial substances and preparations, or other biological substances (with release of deadly biological strains into the environment); in waterways (with heavy casualties or pollution of port waters, coastal territories, inland water bodies); on pipelines (with mass release of the substances being transported, resulting in explosions, fires or environmental pollution); air crashes (with loss of life, which require search and rescue operations; train collisions or derailment (subway trains) resulting in casualties, considerable damage to the railway tracks or installations in the surrounding settlements); at major power plants, systems and in power mains; at waste disposal plants; and hydrodynamic accidents (dam breaks); etc.

Between 1901 and 2007, 1,125 technogenic disasters occurred in the world, affecting about 4.5 million people, of whom around 49,000 died. The total damage was estimated at $225 billion. Such emergencies occurred most frequently in Asia (651 occurrences) and much rarer in Europe (199) and North and South Americas (177). Some estimates indicate that hundreds of thousands of technogenic incidents occur in the world annually, killing hundreds of people, and causing substantial damage that exceeds tens of thousands of US dollars.

According to the UN, technogenic disasters rank third by the number of casualties after natural calamities caused by weather or geological factors. CRED statistics show that the number of technogenic disasters has been growing steadily since the late 1970s. Experts believe that the main reason for this growth is the increasingly sophisticated engineering systems used by people along with a dramatic increase in the number of functions they perform (automation), while the level of knowledge and training of those who design such systems and those who make and operate them fails to meet the standards of work at all stages of their life cycle. CRED statistics indicate that transport accidents, especially at sea and on rivers, have become particularly frequent. Since Europe and North America have a reliable and safe transport and industrial infrastructure, the biggest casualties in such accidents are sustained by poor nations in Asia and Africa. Between 1994 and 2003, the level of casualties as a result of transport accidents in industrialized countries was less than one death per one million people, while it exceeded three in all the other states.

According to the consulting firm Risk Management Solutions, the number of big technogenic disasters has increasingly exceeded the number of natural ones in the past several decades, even though the latter account for 80% of the damage caused. In 2003–2006, the number of technogenic disasters exceeded the number of natural cataclysms several times, with the death rate from them growing steadily. Following below are some of the data regarding the main types of technogenic disasters and their consequences that have occurred in the contemporary history of mankind.

Technogenic emergencies are believed to be caused most frequently by explosions and fires that often occur at industrial facilities, enterprises that mine, store, or process flammable, combustible, and explosive substances; in the coalmines, underground workings, on trains, motor and water transport, pipelines used for the transportation of liquid and gaseous fire- and explosion-hazardous products; as well as in dwelling, social, and cultural buildings and installations. The main causes of technogenic fires are operating practice breaches and fire safety violations, technical defects leading to ignition, human negligence, and (or) malicious intent.

Here are some of the examples of destructive technogenic fires that occurred in peacetime last century: December 30, 1903, Iroquois Theatre, Chicago, USA, (more than 600 people died); October 14, 1913, coalmine in Mid Glamorgan, Wales, Great Britain (439 people died); November 28, 1942, a nightclub in Boston, USA (about 500 people died); September 2, 1949, Chongqing slums, China (more than 1,700 people died); August 20, 1978, a movie theater in Abadan, Iran (more than 400 people died).

Peacetime explosions occur as a result of human mistakes and miscalculations, high concentrations of flammable gases and explosive dust in the air, operating practice breaches during transportation of flammable and explosive materials, violations of the rules of handling (production, storage, transportation, and disposal) of explosive substances and ammunition, as well as terrorist acts. A number of big explosions have occurred in contemporary peacetime history, claiming hundreds of lives and leaving thousands of people injured. These include (number of deaths in parentheses) unprecedented explosions at the Courrières mine in France on March 10, 1906 (1,060), at coalmines in Manchuria, China, on February 12, 1931 (3,000) and at an arms depot in Lianzhou on April 25, 1942 (1,549); at a mine in Johanngeorgendstadt, East Germany, on November 29, 1949 (3,700); in a convoy with dynamite in Cali, Colombia, on August 17, 1956 (1,100); and in the Salang tunnel, Afghanistan, on November 2, 1982 (1,000–3,000).

The majority of experts believe that big plane crashes (Table 2.1), which resulted in loss of life and considerable damage, were caused by engine malfunctions, aircraft element breakdown during the flight, control, power supply, communication, or piloting system failures, a shortage of fuel, crew and passenger life support disruption, piloting mistakes, bad weather, collisions with objects in midair, terrorist acts, and destruction by combat weapons.

Railroad accidents (derailment, collisions, hitting obstacles at railroad crossings, fires and explosions on the train) are caused by track defects, rolling stock, signaling, centralization and blocking equipment malfunction, railroad line and train overload, traffic operator's mistakes, or engine driver's inadvertence or negligence. Following are some of the big peacetime train crashes (the number of deaths in parentheses) that occurred on May 22, 1915 in Gretna, Scotland, (227); on December 12, 1917 near the town of Modane, France, (800); on July 9, 1918 in Tennessee, USA, (101); on March 2, 1944 near the town of Salerno, Italy, (521); on April 3, 1955 near the city of Guadalajara, Mexico, (300); on June 6, 1981 in Bihar, India, (500); and on January 13, 1985 in Ethiopia (392).

Statistics for peacetime casualties on water transport are just as strikingly gloomy. According to the International Association of Classification Societies, 1,226 ships and 8,777 people were lost in 1990–1996 as a result of sea accidents alone (Table 2.2). On June 15, 1904, the pleasure boat General Slocum was completely destroyed by fire on the East River, New York, USA (1,030 people died); on April 14–15, 1912, one of the world's biggest passenger liners, Titanic, sank after a collision with an iceberg in the North Atlantic (1,503); on September 28, 1912, the Japanese steamship Kichemaru sank off Japan (1,000); on May 29, 1914, the British steamer Empress of Ireland sank on the St. Lawrence River after a collision with a Norwegian coal freighter (1,012); on February 26, 1916, the French cruiser Provence sank in the Mediterranean (3,100); on December 6, 1917, the French Mont Blanc carrying munitions and the Belgian steamship Imo collided (causing a big explosion) and sank in Halifax Harbor, Canada, (1,600); on March 18, 1921, the Hong Kong sank in the South China Sea (1,000); on April 14, 1944, the Fort Stikine carrying munitions exploded in Bombay Harbor, India (1,300); on

Table 2.1 Some of the significant air crashes (1953–1998)

Date	Description	Casualties
May 3, 1953	The world's first jetliner Comet-1 G-ALYV crashed during a violent storm, Calcutta, India	43
March 16, 1969	DC-9 plane crashed after takeoff in Maracaibo, Venezuela	155
July 30, 1971	A Boeing-727 passenger liner collided with an F-86 combat plane over Morioka, Japan	162
October 13, 1972	Il-62 passenger plane belonging to East German airlines crashed near Moscow when making a landing approach in bad weather	176
January 22, 1973	A Boeing-707 passenger liner crashed after fire when landing at Cano, Nigeria	176
March 3, 1974	A Turkish DC-10 plane crashed near Paris due to cargo bay depressurization	346
August 3, 1976	A Boeing-707 passenger plane flew into a mountain near Agadir, Morocco	188
March 27, 1977	Two Boeing-727 planes collided on the runway at Tenerife, Canary Islands	582
May 25, 1979	A DC-10 passenger plane crashed during takeoff at O'Hare International Airport in Chicago, USA	275
August 19, 1980	A TriStar plane belonging to Saudi Airlines was destroyed by fire after an emergency landing in Al-Riyadh, Saudi Arabia	301
September 1, 1983	A South Korean Boeing-747 passenger liner was downed after violating Soviet airspace	269
August 12, 1985	A Japanese Boeing-747 passenger liner flew into Mount Ogura, Japan	520
July 3, 1988	An Iranian A-300 passenger plane was downed over the Persian Gulf by a U.S. warship	290
September 3, 1989	A Cuban Il-62 airliner crashed near Havana, Cuba	214
July 11, 1991	A Nigerian DC-8 plane crashed when landing in Jeddah, Saudi Arabia	261
November 12, 1996	An ascending Saudi Boeing-747 collided with a landing Il-76 plane belonging to Kazakh Airlines near New Delhi's airport, India	372
September 26, 1997	An Indonesian A-300-B4 airliner crashed in the mountains not far from Medan, Sumatra, Indonesia	234
September 2, 1998	A Swiss McDonnell-Douglas plane crashed near Halifax, Canada	229

November 12, 1948, a Chinese army evacuation ship sank off Manchuria (6,000); on September 26, 1954, the Japanese ferry Toya Maru sank in the Tsugaru Strait, Japan, (1,172); on December 20, 1987, the Philippine ferry Dona Paz and the tanker Victor collided in the Tablas Strait, the Philippines (3,000); on September 28, 1994, the Estonian passenger ferry Estonia sank in the Baltic Sea (912).

Table 2.2 World sea accident statistics (1990–1996)

Years	Number of ships lost	Number of people killed
1990	149	807
1991	174	1,389
1992	175	986
1993	178	915
1994	181	1,478
1995	183	1,312
1996	186	1,890
Total	1,226	8,777

There are hundreds of big nuclear energy and chemical enterprises in the world and the accumulated nuclear and chemical stocks are enough to destroy all living beings on earth several times. The most dangerous are emergencies at radiation and chemically hazardous facilities, as evidenced by the world's biggest chemical and nuclear accidents (close to disaster in magnitude) that occurred in Bhopal, India, in 1983 and at Chernobyl, USSR, in 1986.

According to estimates, about seven million artificial toxic substances have been produced in the world since the beginning of mankind, and 60,000–70,000 of that amount are in close contact with people or close to their residential areas, thus creating the risk of chemical accidents and disasters.

A chemical accident (disaster) is a violation of production processes at chemical facilities accompanied by damage to and (or) destruction of pipelines, tanks, storage facilities, or transport means, which result in a release of chemically hazardous substances into the atmosphere or biosphere, endangering biocenosis and the lives and health of people. In addition, under certain circumstances some nontoxic substances emerging during a chemical accident (explosion, fire) can produce chemically hazardous substances. In the event of a chemical accident, the surface layer of the atmosphere, sources of water, soil, and food get polluted. Chemical, pulp-and-paper and processing factories, mineral fertilizer enterprises, ferrous and nonferrous metallurgy plants have large stocks of chemically hazardous substances. The biggest number of chemical accidents occurs at enterprises that make or store chlorine, ammonia, mineral fertilizers, herbicides, and products of organic and petroleum organic synthesis.

Bad chemical accidents and disasters occur in the world with enviable regularity. In 1976, an accident at an Italian plant in Seveso led to dioxin pollution of over 18 km^2. More than 1,000 people were affected, and many animals died. The clean-up operation took 18 months. 2 years later, 28 tons of sodium cyanide leaked into the local river as a result of an accident at a chemical plant in Suzhou. This would have been enough to poison tens of millions of people, but, luckily, only 3,000 were affected.

One of the most tragic chemical disasters of the twenteith century was an explosion at a Union Carbide plant in Bhopal, India, on December 2, 1984, which killed more than 4,000 and poisoned over 40,000 people. A cloud of 43 tons of methylisocyanate (it is 2–3 times more toxic than phosgene) released from the plant by the explosion covered an area of tens of square kilometers, causing mass deaths.

In 1988, an extremely toxic rocket fuel, unsymmetrical dimethylhydrazine (heptyl), spilt during a railroad accident in Yaroslavl, USSR. About 3,000 people happened to be in the hazardous zone. A year later, about 7,000 tons of liquid ammonia spilt at a plant in Jonava, Lithuania, forming a lake of about 10,000 square meters. No one was affected only due to favorable meteorological conditions. Finally, 32 tanker cars with liquid chlorine derailed in Mexico in 1991. Specialists say that 300 tons of the chemical escaped into the atmosphere. As a result, about 500 people were affected, and 17 of them died at the scene of the accident. More than 1,000 people were evacuated from the nearest town.

Nowadays, practically every industry and field of science uses radioactive substances and sources of ionizing irradiation (nuclear materials) in increasingly growing amounts. Nuclear power generation is developing particularly fast. While opening up big energy and other prospects, nuclear facilities and technologies create big risks for people and the environment. Nuclear materials have to be stored, transported, and processed. All these operations create additional risks of radioactive contamination of the environment and harmful effects for people, plants, and animals. Import and disposal of spent nuclear fuel is another acute problem.

A radiation accident is an emergency resulting in a loss of control of radioactive material due to a natural disaster, equipment failure, unskilled actions of personnel, or other factors, which leads or may lead to radioactive poisoning of people or radioactive contamination of the environment. Radiation accidents occur at radioactive hazardous facilities or during transportation of cargoes containing sources of ionizing irradiation. Although big radiation accidents occur relatively rarely, their emotional impact on the population can hardly be overestimated.

Several nuclear accidents (disasters) have happened in the history of mankind since the start of the nuclear era: 1957 – an explosion at a nuclear waste storage facility leading to extensive radioactive contamination of an area of 15,000 km^2 and evacuation of the local population (Chelyabinsk region, USSR); the burning of graphite rods at the nuclear power plant in Windscale, England, where 500 km^2 were affected by radioactive contamination; 1979 – meltdown of the reactor core at the Middletown nuclear power plant (Three Mile Island, Pennsylvania, USA), releasing large amounts of radioactive contamination; 1981 – a spill of 400,000 l of radioactive coolant at the Sequoyah one plant in Tennessee, USA; 1986 – the world's biggest disaster at the Chernobyl nuclear power plant in Ukraine, USSR, where an uncontrolled acceleration of the reactor and the ensuing reactor core explosion released several million cubic meters of radioactive gases, which spread all over the European part of the continent. More than 20,000 km^2 were contaminated with radiation. All people were evacuated in the radius of 30 km from the scene of the accident (including forced relocation of 100,000 people from the town of Pripyat). In addition to environmental damage, nuclear accidents also cause tremendous social, economic, moral, ideological, and political impact on society.

Accidents at waterworks facilities are relatively rare. However, their consequences, especially under unfavorable circumstances, can be compared to those of meteorological disasters. For example, when a dam or a hydroelectric complex falls apart, this creates a real threat of inundation in lowland areas similar to that caused by violent cyclones. The height and the speed of the resulting wave depend on the extent of the damage to the hydroelectric facility and the height of its bottom and top barriers. The break wave moves at a speed of 3–25 km/h in plain areas, and up to 100 km/h in mountainous areas. As a result, considerable parts of territory get flooded within 15–30 min after a burst and end up under water 0.5–10 m deep, which can stay from several hours to several days.

Hydroelectric plant dam bursts, including those under construction, happen rarely. Only three such incidents have been registered in the world over the past 10 years: on May 27, 2004, the dam of the Dalongtan hydroelectric plant on the Qingjiang River broke within the boundaries of the city of Enshi (as a result, a minibus with 14 people was engulfed); on February 11, 2005, water rose dramatically due to heavy rains, breaking the dam in the province of Balochistan in the southwest of Pakistan and causing a flood that washed away several villages (more than 50 people died and 500 disappeared), and on October 5, 2007, a typhoon-caused flood broke the dam at the Cua Dat hydroelectric plant under construction on the Chu River in the Vietnamese province of Thanh Hoá.

Environmental disasters occupy a special place among technogenic disasters as they have extensive harmful effects on the environment and biosphere. In addition to the causes mentioned above, environmental incidents, accidents, and disasters are caused by gross safety violations, negligence on the part of the administration and personnel at potentially hazardous industries, political and administrative ambitions, greed, economy drives, and withholding of information about technogenic emergencies. On the basis of this definition, anthropogenic environmental disasters may include explosions, fires, and transport accidents if they release polluting, toxic, or radioactive substances into the atmosphere and biosphere in exorbitant amounts. In addition to those cited above, the most vivid examples of technogenic environmental disasters include an oil blowout at an oil platform in Santa Barbara

Bay (California, USA) on January 28, 1969, when about a million liters of oil spilt into the sea over 11 days; a release of a poisonous dioxin cloud into the air as a result of an accident at a chemical plant in Seveso, Italy, on July 10, 1976, which necessitated the evacuation of the local town for 18 months; and an accidental atmospheric release of anthrax spores at the Institute of Microbiology and Virology in Sverdlovsk (USSR), which contaminated an area over a radius of 3 km and killed several people.

Hundreds of emergencies occur in Russia nowadays. The cost of ensuing cleanup operations accounts for more than 15% of the national domestic product. If this tendency persists, very soon the national economy will not be able to carry out postcrisis rehabilitation. Since two-thirds of such emergencies have a technogenic origin and are caused by anthropogenic activities, studying their nature, developing a theory of their occurrence, and working out measures to mitigate their consequences has become a pressing scientific and practical task in Russia.

2.2 Man-Made Disasters and Emergencies in Russia: Causes and Consequences

In order of decreasing number and frequency the man-made disasters and emergencies in Russia are distributed as follows [1]: disasters at industrial facilities, road traffic accidents, motor vehicle breakdowns, emergencies in residential and social function buildings, at nuclear facilities, and chemical disasters. Their main causes are:

- engineering systems' failure resulting from inadequate workmanship and violations in operating procedures (for instance, many modern potentially dangerous facilities are designed so that the major accident probability at the facilities is rather high, being estimated at 0.0001 and higher; in real life, however, accidents at these facilities occur much more often);
- mistakes of engineering systems' operators. The statistics show that more than 60% of accidents result from erroneous actions of the operating personnel;
- concentration of various production facilities in industrial zones without due study of their interaction and mutual influence;
- high power supply level of the engineering systems;
- external deleterious impacts on power, transportation, and other facilities.

Also, there is a class of so-called "geo-technical systems" whose failure results from a synergic interaction of an engineering system and the environment.

The variety and complexity of subject–object interactions leading to emergencies in Russia are shown in Fig. 2.2. In the course of a further analysis of Russia's man-made disasters and emergencies we shall abide by this scheme in order to systematically evaluate the risks resulting from inadequate functioning of the country's facilities in power supply, transport, and industrial infrastructure.

Looking back, according to unofficial information of the Russian Ministry of Emergencies and the Federal Service for Ecological, Technological and Nuclear

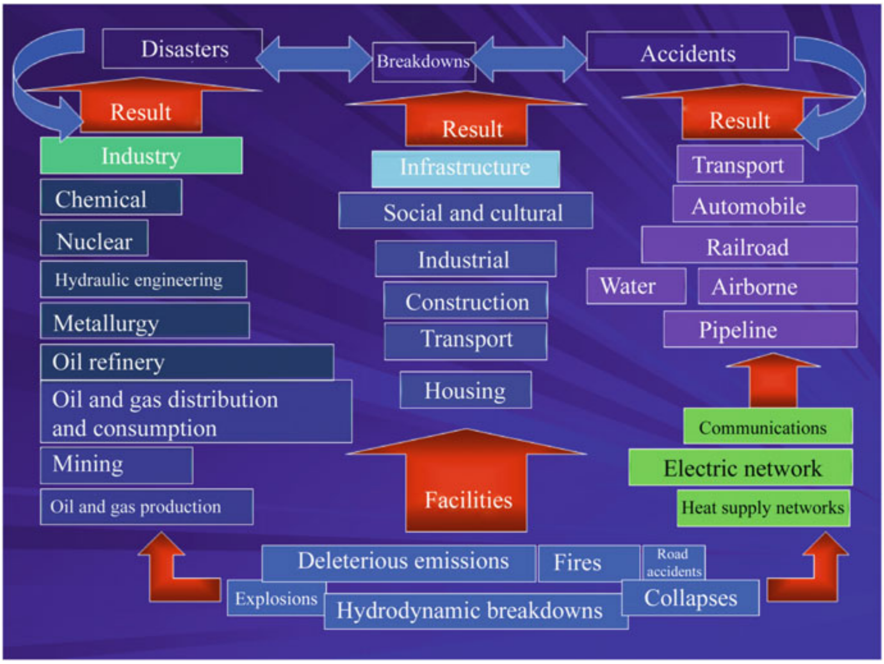


Fig. 2.2 Subject–object man-made disasters in Russia

Monitoring (ROSTEKHNADZOR) [2], in 2006 the bulk of Russia's man-made disasters were related to fires in buildings and structures (back then, in 10 months alone 1,547 major fires occurred with a death toll of 3,522). Statistically, during this period, every 5 min a fire broke out in the country, every hour one man died in a fire and 20 sustained burns and injuries; 44 major traffic accidents occurred with more than 10,000 casualties; there were 38 air crashes in which 296 people died, 15 railway wrecks with five dead, and 18 accidents on water (11,019 dead). In 11 months of 2008, 162 accidents occurred at the country's industrial facilities: 34 on oil and gas extraction sites and main pipelines, 13 at petroleum and chemical plants and oil refineries, 12 in coal production, 10 in the chemical industry, 7 in the mining industry, 4 each in metallurgy and botanical raw material processing and storage. The total casualties in those accidents reached 414.

Overall, in recent years the man-made hazard in Russia is presented by such emergencies as fires and explosions at dangerous production facilities and residential buildings, road accidents, accidents at main pipelines, communal utility and power supply facilities, and emissions of chemically dangerous compounds. Because of the general wear and exhaustion of designed service life of many technological systems of thermoelectric plants and boiler stations, and incomplete preventive and maintenance measures on account of underfunding, the number of accidents at them, including fire, is also growing.

Table 2.3 Man-made disasters and emergencies in Russia

Branch of Russia's industry	Number of accidents by year		
	2003	2004	2005
Metallurgy	4	3	No data
Mining and nonmining industry, underground construction facilities	14	14	No data
Coal production	30	35	No data
Mining industry	44	40	No data
Chemical industry	No data	11	27
Nuclear industry	No data	No data	No data
Oil and gas production facilities	No data	20	16
Main pipeline facilities	No data	48	45
• pipelines	No data	29	19
• gas supply lines	No data	19	19
• oil pipelines	No data	-	3
• oil products pipelines	No data	-	4
Hydraulic facilities	-	1	-

Given below [2] are summarized statistical evaluations of man-made disasters and emergencies in Russia's main industries during 2001–2004 (Table 2.3). According to "ROSTECHNADZOR," in the past 5 years 62 accidents of this type took place. Resulting material damage exceeded US$ 3 billion. The principal causes were physical wear of the main production equipment and structures, inadequate supervision by the facilities' monitoring services of the technical condition of the equipment, and violation of operating rules and safety regulations.

In the past 30 years the number of accidents in the metallurgical and chemical-recovery coke industry has grown by 2.5, the number of casualties by six, and the economic damage by 11 times (Table 2.3). In 2007 alone, two accidents occurred there with 17 casualties. The economic damage amounted around US$ 10 million. The principal causes were violation of service instructions in the metallurgical processes (33.4%) and technical faults of the equipment.

In recent years, Russia's underground and open cast mining industry witnessed a buildup of production and an increase in the penetration and extraction depth. This increased the danger stemming from the deteriorated mining and geological conditions. In 2006, the material damage from accidents in this area alone exceeded

US$ 40 million. Two thirds of the accidents that took place in underground works (four fires and one explosion in mines) were caused by "the human factor," i.e., inadequate safety engineering, lack of production control, violation of technological and labor regulations, and careless or unauthorized activities of operators. (Table 2.4)

The statistics show that mining production in Russia proceeds with an unjustifiable risk so that each million tons of coal costs one miner (Table 2.5). The industry's experts admit that around 80% of cases of the general injury rate and 60% of lethal cases are the result of violations in the technological process, in discipline and safety engineering. The damaging factors at Russian mines include collapse, equipment failure, transport malfunction, power outage, geodynamic phenomena, and methane explosions (the public is informed about the gas hazard of the Russian mines because of the heavy casualty effect of each such explosion as compared to other types of accidents). Each year, around 30 methane explosions occur at Russia's mines with tens of casualties (100 dead in 2003, 148 in 2004).

Table 2.4 Accidents and lethality rate at Russia's metallurgical plants from 1998 to 2007

Year	Amount of production, million tones	Number of accidents	Number of lethal cases
1998	132.1	5	26
1999	148.2	5	36
2000	177.8	4	33
2001	158.7	6	27
2002	168.6	4	23
2003	176.1	4	24
2004	181.3	3	22
2005	188.6	2	21
2007	184.0	2	17
Per years	168.4	3,9	25,4

Table 2.5 Accidents and lethality rate at Russia's mining industry in 1997–2007

Years	Coal production, million tones	Number of accidents	Lethality
1997	244.4	56	242
1998	232.4	54	139
2009	249.1	39	104
2000	254.2	34	115
2001	266.4	34	107
2002	234.2	27	83
2003	270.3	30	109
2004	287.5	35	148
...	...	...	...
2007			219

Despite the fact that year 2008 witnessed relatively low lethality rate in the mining industry when considering the past decade, two major disasters occurred in 2009 at mines of the Kemerovo region with 150 casualties. Thus, the accident rate and number of lethal injuries in Russia's mining industry kept growing each year of this century. Man-made lethal accidents exceeded 50% of the total losses (Fig. 2.3).

Russia today has over 3,000 chemically dangerous facilities. One hundred and forty-six towns with population of more than 100,000 people are located in chemically dangerous areas. There are more than 9,000 plants of chemical, petrochemical, and oil refining industries, 7,700 of which are organizations using hazardous industrial facilities. From 1992 to 1996 more than 250 accidents occurred at such facilities, during which time more than 800 people sustained injuries and 69 died. In 2005, 27 accidents occurred at the facilities of chemical, petrochemical, and oil refining industries, in which 41 people died. Seventy-three percent of casualties occurred in pouring and discharging operations, during container cleaning and repair.

The principal causes of disasters at the chemical facilities were inadequate condition of engineering systems, buildings and structures resulting from ageing of production assets. Other contributing factors were low rate of modernization of the industry, incorrect organization and violation of operating procedures, inefficient production management, deliberate disconnection of protection systems, defiance of production discipline, and careless or unauthorized actions of the operating personnel. As a result, a fourth of all accidents were caused by beyond-limit use of obsolete and worn equipment, inoperability of test instruments, and "the human factor."

Fig. 2.3 Fire at one of the chemical plants

The situation in Russia's oil and gas production and refining industries is also rather perilous. For instance, in addition to explosions and fires at the oil and gas production facilities, falls of drilling derricks and drill string-ups during deep drilling and repair of boreholes (Table 2.6), each of the last 2 years witnessed oil and gas blowouts. In 2008 alone, two such blowouts occurred at the Anastasyevsko-Troitskoye deposit in Krasnodar region and one at the Fyodorovskoye deposit in Khanty-Mansi autonomous territory. The preconditions for such disasters also exist at other deposits in West Siberia. The open (uncontrolled) oil and gas blowouts reduce the bedding energy and cause irreversible loss of much of the resources. In addition, Russia still doesn't utilize the associated gas but burns it (30% of the extracted amount). This is not only a direct loss to the national economy, but also a permanent threat to environment.

The main problem in providing safety at oil and gas production and refining facilities is the slow rate of upgrading of obsolete equipment and that with exhausted service life. The main causes of accidents and injuries in operating such facilities are typical of Russia and result from the low professionalism and work discipline of the personnel using it.

By virtue of its geographical position and the specific economic development, Russia has the world's longest main pipeline system. The state-owned network of oil and gas pipelines together with oil and gas production and transportation infrastructure covers 35% of the country's territory where 60% of its population live. The main pipelines are the most capital-intensive facilities of the oil production industry. The average length of oil transportation lines in Russia exceeds 2,000 km (800 km in the U.S.). By year 2006 more than 40% of Russia's main pipelines exceeded the accepted service life of 33 years. Over 400 pump stations and 900 tanks operate at the oil pipelines of Russia. The gas pipelines use, respectively, over 250 compressor stations and 21 underground gas storage facilities with a total capacity of more than 80 billion cubic meters.

Special classes of danger are pipeline transit sections installed on natural and man-made obstacles such as rivers, reservoirs, railways, and motor roads. The gas pipelines have more than 1,175 underwater transits with a total length of 3,500 km. Over 40% of tunnels have been laid more than 25 years ago. As of 2005, the total length of the linear part of the main pipelines was more than 231,000 km, of which 161,100 km are main gas pipelines, 49,000 km are main oil pipelines, 19,500 km are main product pipelines, and 1,400 km are ammonia pipelines.

Table 2.6 Causes of disasters in Russia's oil and gas production industry

Types of disasters	2004	2005
Open fountains and injections	6	5
Explosions and fires at facilities	7	5
Fall of derricks and disintegration of their components	1	2
Fall of drill string-ups during deep drilling and underground repair of boreholes	2	1
Other	4	3
Total	20	16

The annual number of emergencies on Russian high-risk pipelines reaches 5,000–6,000. In terms of modern ecological requirements and safety rules their further operation becomes unpredictable and uncontrollable because of the landslide pattern in accident occurrence, which is now 0.4 per 1,000 km (120 accidents per year). According to the studies carried out by JSC GAZPROM, TRANSNEFT Joint Stock Company, RAO Russian Oil and Gas Production Company NEFTEGAZSTROY, the current condition of oil and gas transportation facilities located in West Siberia is unpredictable which is the cause of the growing rate of accidents on the field and main pipelines that lack due engineering forecast (along with ineffective anticorrosion measures) and ecological monitoring of the environment in areas where oil and gas production facilities are located.

Accidents of Russia's gas pipelines occur rather often. Every year, around ten of them occur on major gas pipelines alone. In most cases (the 2007–2008 statistics are shown in Table 2.7) such accidents do not lead to casualties, though many of them (in 50% of cases) are followed, as a rule, by large-scale fires. Table 2.8 shows data for the main causes of such disasters, among which the following must be pointed out.

1. Formation, in some portions of the main pipelines, of erosion patches 3–10 m deep and up to several hundred meters long. Dangerous sags and deformations occur, which dramatically increase the risk of a disaster. As a result, 15% (over 20,000 km) of main pipelines are used with a reduced pressure in order to avoid a rupture.
2. Intense development of stress-corrosion processes on large diameter pipes associated with degradation of the insulation film coating of main pipelines many of which had been built 20 and more years ago. So, whereas in 1991–1996 the share of accidents for this reason made up around a fourth of the total balance of the JSC GAZPROM accident rate, in the period from 1998 to 2003 it made up a third and, in 2005, more than half of all accidents.
3. Insufficient overhaul and inadequate fitting of main transport pipelines with tele-mechanics and automation systems.
4. Commissioning gas distribution stations currently not included in the unified gas supply system.
5. Considerable growth of instances of unauthorized tapping of oil, oil products, and gas pipelines for theft of the transported products.
6. Accidents through inadequate workmanship in the course of construction and installation during the construction boom (1970–1980s) on the main pipeline facilities by construction organizations that did not have the required equipment.

As a result, annually Russia sustains losses from accidents, gas leaks, and oil spills equal to 6–8% of the total market value of the annual production of those products less the cost of recovery of the environment.

A positive point is some reduction, in the past 2 years, of the accident rate on main and field pipelines. This became possible due to allocation of the required funds for repairing the lines and diagnosing their condition. However, as before, minor accidents occur because of mechanical disturbances, theft of transported

Table 2.7 Emergencies at Russia's main gas pipelines during 2007 to 2008

Emergency date	Brief description of emergency	The afflicted
3 April 2007	A rupture and fire at main gas pipeline Urengoi-Center-2 in Khanty-Mansi autonomous territory	No afflicted personnel
7 April 2007	A repeat rupture with ignition of a pipe at Urengoi-Center-2 main gas pipeline. The emergency occurred in preparation for commissioning of the pipeline's main branch	No afflicted personnel
3 June 2007	Rupture of a pipe in the Ukhta-Torzhok main gas pipeline and a fire in a forest in Tutayevsky district of Yaroslavl region	No afflicted personnel
3 July 2007	Rupture of a portion of the Yamburg-Zapadnaya Granitsa pipeline in Arsk district of Tatarstan, gas explosion and a subsequent fire. The high temperature at the site of the fire caused a depressurization of two more pipelines, Yamburg-Yelets-1 and Yamburg-Yelets-2 with a subsequent torch burning of methane (torch height 20–30 m, burning area around 100 square meters)	No afflicted personnel
26 July 2007	Explosion and fire on a main gas pipeline in Vsevolzhsky district of Leningrad region in Severnaya TETs Petersburg-Lavriki zone. The accident was accompanied by a heavy blowout of flame and smoke which took the form of a thunder storm, which caused panic among the local population. At the emergency site the forest and peat bog caught fire over an area of around two hectares	No afflicted personnel
28 September 2007	Rupture of main pipeline without ignition in Krasny Yar settlement of Sverdlovsk region	One person injured
1 December 2007	Rupture of the main pipeline Srednyaya Aziya – Tsntr (Middle Asia – Center) with subsequent ignition of remotely located villages in Alekseyevsky district of Volgograd region	No afflicted personnel
13 January 2008	An explosion and fire (height of flame column several meters) on main gas pipeline in Tosninsky district of Leningrad region. As the fire was localized, around 0.5 ha of surrounding terrain had burnt out	No afflicted personnel
16 February 2008	Rupture and ignition of a main gas pipeline Yamburg-Yelets-1 in Oktyabrsky district of Khanty-Mansi autonomous territory	No afflicted personnel
17 February 2008	Rupture and fire at main gas pipeline in Novgorod region between Valdai and St. Petersburg. Two private houses, located 100–120 m from the rupture site, burned down	No afflicted personnel
22 April 2008	Rupture of main gas pipeline Yamburg-Tula-2 in Nizhny Novgorod region 3 km off the Pilna compressor station	No afflicted personnel
24 July 2008	A rupture of a main gas pipeline with subsequent ignition in Volgograd region 300 m off the railway. Five districts of Volgograd region were left without gas	No afflicted personnel
24 July 2008	Two disasters with ignition at gas pipelines running across Khanty-Mansi autonomous territory: on main gas pipeline Yamburg-Yelets-1 and main gas pipeline Punga-Ukhta-Gryazev	No afflicted personnel
25 July 2008	A rupture with ignition occurred on the 627 th km of the gas pipeline Yamburg-Yelets-2 150 km north of the town of Beloyarsk of Khanty-Mansi autonomous territory	No afflicted personnel

(continued)

Table 2.7 (continued)

Emergency date	Brief description of emergency	The afflicted
14 August 2008	A rupture of a main gas pipeline with subsequent ignition of Nekrasovsky district of Yaroslavl region	No afflicted personnel
5 October 2008	A rupture of a main gas pipeline in Shchelkovsky district of Moscow region. No gas ignition occurred	No afflicted personnel
24 December 2008	A rupture and fire on a branch of the main gas pipeline Gryazovets-Petersburg in Volkhovsky district of Leningrad region	No afflicted personnel

Table 2.8 Main causes of accidents on main pipelines in Russia

Troubles	Gas pipelines	Oil pipelines	Products pipelines	Total
External mechanical impacts, including:	3	12	5	20
–tapping;	-	8	1	9
–construction systems	3	4	4	11
Corrosive destructions	14	-	-	14
Faults in construction and installation	3	2	-	5
Personnel errors	1	-	1	2
Manufacturing fault	2	2	-	4
Total	23	16	6	45

products, faults in construction and installation, violation of design regulations, and corrosion of pipes, fittings, and control appliances. As usual, the main pipelines remain vulnerable to terrorist acts, the probability of which is still rather high.

The coverage of emergencies on Russia's hydraulic facilities that occurred in the past decade (Table 2.9) should start with the 17 August 2009 disaster on the country's largest Sayano-Shushenskaya hydroelectric plant (Fig. 2.4) on the Yenisei River in Siberia. The disaster in the form of an inrush of water into the plant's engine room without collapse of the dam and flooding of residential areas was stopped. But it brought about the death of 75 personnel and fully destroyed three power sections of the plant. This heavily impacted the power supply of Siberia and neighboring regions. The recovery, estimated at more than one billion Euros, will take, according to experts, no less than 4 years.

Prior to the August 2009 disaster, only one accident in the last 30 years of operation had occurred at the Sayano-Shushenskaya plant. It was in spring of 1985. Back then, during powerful flooding the water from Yenisei rapidly washed out the concrete and metal framework of the dam thus leading to destruction of 80% of the

Table 2.9 Accidents at Russia's hydraulic facilities from 2001 to 2009

Accident date	Brief description of accident	Consequences
10 October 2001	Accident and fire at substation of Irkutsk power plant following an earthquake at Baikal	No consequences
11 March 2004	Accident at GES-10 power plant on the Vuoks River in Svetogorsk, Leningrad region, which threatened to flood a town of around 15,000 people	No consequences
6 February 2006	While lifting a transformer at Bureiskaya GES plant in Talakan, Amur region, a bridge crane broke down. Upon falling, it crushed the plant' water supply line	No consequences
19 August 2006	At Bureiskaya power plant in Talakan, Amur region, through a mistake by the plant's personnel's a hydro-unit block transformer was not useable for over a month	No consequences
13 June 2007	Fire at Zhigulyovskaya power plant in Samara region	No consequences
12 September 2007	Fire at a block transformer of Novosibirsk power plant	No consequences
8 October 2007	Damage to 500-kV power transmission lines of Bureiskaya plant caused by a rain cyclone and strong winds	Fan-type power outage of facilities in Khabarovsk
27 February 2008	Ignition on the roof of Rybinsk power plant in Yaroslavl region	No consequences

water discharge channel. Other contributing factors of the destruction were previous inadequate research, development, and installation work.

The damage from all accidents on Russian hydroelectric plants in 2001–2009 (less the Sayano-Shushenskaya disaster) exceeded US$ 80 million.

Investigating the accident rate in Russia's nuclear industry, which incorporates many enterprises for extraction, enrichment, and processing of uranium, as well as nuclear power plants, defense organizations, the authors seek, for some reasons, not to supply detailed statistics. Most experts believe that the principal source of man-made threats is the nuclear industry, functioning now for over half a century, with its danger of ecological disasters (like the one in Chernobyl) originating from radioactive emissions during blowouts.

Among the faults and problems in the work of ROSATOM (Russia's Nuclear Energy State Corporation) the most conspicuous are the slack discipline and eroded professional skills of the nuclear heat production industry personnel. Many violations and accidents, detected each year by ROSTECHNADZOR, are caused by human factor. At the same time, the main equipment continues to wear whereas its modernization is thwarted by financial constraints. The problem of processing and handling radioactive waste is not being addressed. In the course of operation, Russian nuclear plants emit into the atmosphere a large amount of such dangerous isotopes as Ts-137,

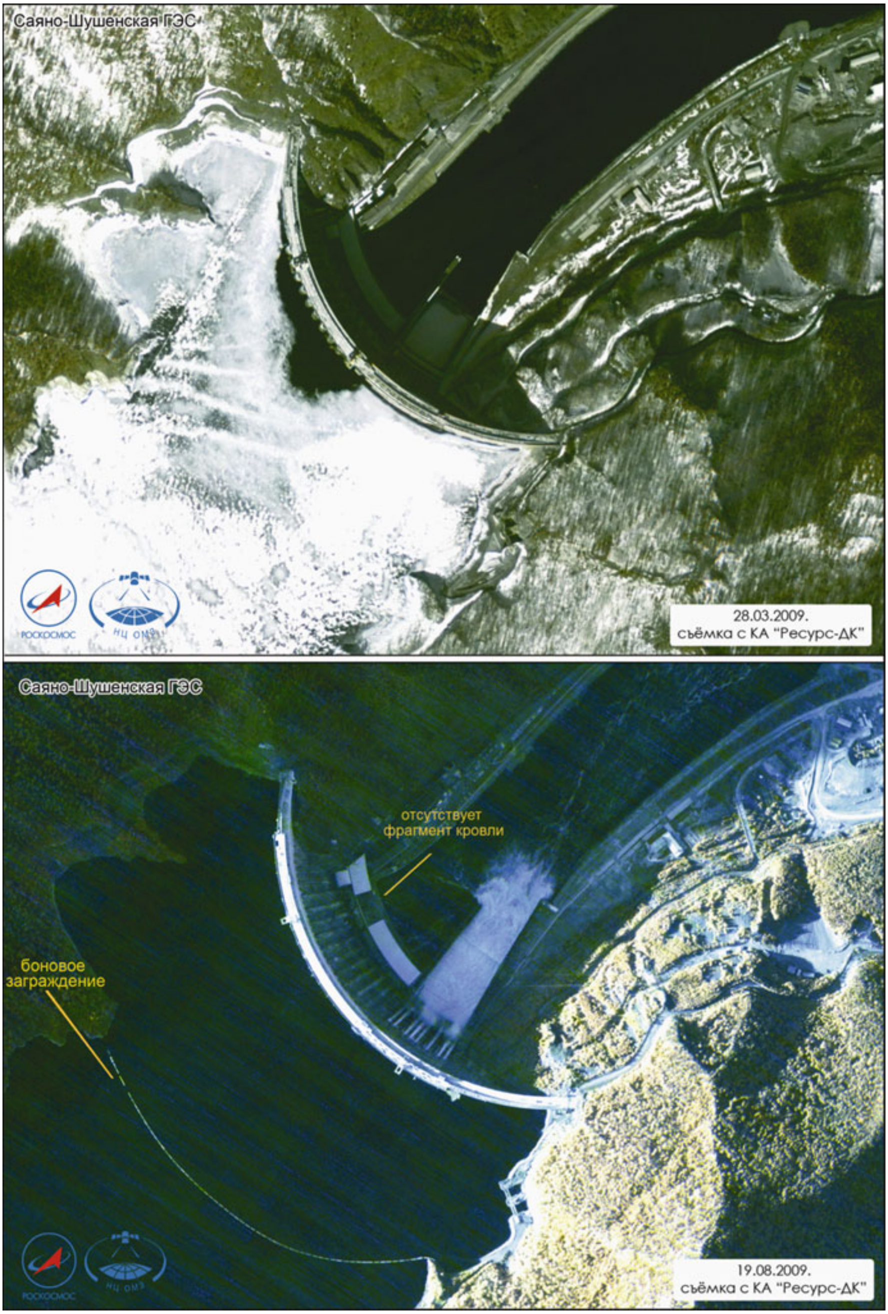


Fig. 2.4 Space images of Sayano-Shushenskaya hydroelectric power plant

I-131, Co-60, and others. Tens of thousands of cubic meters of radioactive water used for cooling the reactors are discharged into neighboring reservoirs. In 2007, at ten Russian nuclear plants 47 malfunctions were registered. Those had been caused by mistakes in design and manufacture of equipment, by neglect of safety regulations, and unprofessional actions of the plants' personnel.

On the basis of the accident statistics for Russia's industries given above, the following conclusions can be drawn.

1. Nine to sixteen accidents of various gravity occur every year
2. The main figures for accidents and casualties per one million tons of "products obtained" are, respectively, as follows:
   - in metallurgy –0.02 and 0.14;
   - in the ore mining industry –0.01 and 0.02;
   - in the coal production industry –0.12 and 0.52;
   - in the mineral resource industry –0.01 and 0.07;
   - in the petrochemical industry –0.004 and 0.005;
   - in the oil/gas production industry based on various estimates –0.03/0.04 and 0.04/0.05;
   - on pipeline transport (for 1,000 km) –0.19 and 0.02
3. Annually, on average, three emergencies occur for each Russian hydroelectric plant, and 4.7 for each nuclear plant.

Considering that 60–70% of accidents are caused by "human factor," in the future their number could be reduced at least by half through active introduction of methods and systems, including those in space that ensure reliability and safety of complex equipment. However, the forecasts of experts of the Russian Ministry of Emergencies unfortunately indicate that in the coming years the number of man-made disasters in the country will grow in geometric progression because of infrastructure ageing and the typically Russian carelessness in construction of potentially dangerous facilities.

The accident rate in the chemical, petrochemical, and oil refining industries may be expected to lessen somewhat because of the tightened supervision by the state of safety at industrial facilities and through their modernization and renovation. The probability of major fires at oil terminals and oil refineries still remains high. Equipping of ecologically dangerous facilities with accident preventive systems at some chemical production plants proceeds slowly, and that may lead to new major disasters in the form of emissions of harmful compounds into the atmosphere and damage to people.

There is still danger that water storage dams may burst and contaminate reservoirs with harmful compounds. To eliminate this danger it is necessary to establish an effective system for monitoring the condition of hydraulic facilities in industry and in the water utility service, to enhance safety, to timely repair and maintain the structures and equipment.

The decisive factor still affecting railroad safety is the wear of the rolling stock and upper structures of the road. The positive factor, however, is introduction on some roads of automatic systems for monitoring dangerous freight traffic.

Unfortunately, the road accident rate doesn't fall in Russia. The gravity of the situation (the number of dead per 100 victims) is still inadmissibly high, 14, whereas in Western countries this figure doesn't exceed five. To a great extent this situation is determined by the poor state of the road infrastructure and the soaring number of motor vehicles belonging to individuals with slack discipline on the road. The problem can be resolved with development of telematic systems and establishment of traffic corridors using space monitoring systems.

The observed trend of negative impacts of man-made disasters in Russia testifies both to the general state of security at the country's industrial facilities and to the influence of other objective factors such as physico-geographic and climatic conditions. In a cold period of the year, such factors essentially increase the load on Russia's power supply systems, contributing to harsh operating conditions, temperature and humidity difference. The periodic freezing and thawing cause soil displacement and other structural disturbance.

Global buildup of temperature is known to be fraught with an array of threats. In the twenteith century the annual mean yearly temperature had grown by 0.6°. In subpolar regions it was still higher, reaching 3–6°. In Russia, vast territories north of Baikal are located in permafrost regions where the thickness of permanently frozen soil varies from half a meter in the south to hundreds of meters in the north. The southern border of multiyear frozen rocks has moved hundreds of kilometers to the north. This applies in the first place to the European part, West Siberia, Yakutia, and the Arctic coast. The permafrost thawing rate under such circumstances reaches 20 cm per year, which impacts geo-engineering structures built on permafrost (main oil and gas pipelines, power transmission lines, railroads, elements of infrastructure, etc.) The thawing of "eternal" ice may cause a massive deformation and destruction of buildings. So, in the last 10 years the number of buildings that sustained different destructive impacts due to the foundation sagging alone increased as compared to the previous decade, by 42% in Norilsk and by 61% in Yakutsk. Their condition must be permanently monitored. Considerable efforts are needed to maintain them in a state of repair.

The growing number and power of typhoons impose a threat for the Far East, the Kurile Islands in the first place. Geomagnetic storms increase the number of mistakes made by operators at all levels. Also, they enhance the risk of failures in sophisticated electronic and electro-mechanic systems. Such risks increase the probability of man-made disasters.

Many major geo-engineering systems, such as main oil and gas pipelines, power generation facilities, motor roads, railways, power transmission lines, factories, towns, and many more, have been built in these sensitive territories. Each year they sustain heavy climatic and geophysical impacts. Under such circumstances it is logical to expect a growth in the number of accidents on those facilities caused, among other things, by chronically insufficient maintenance, improper preparation for heating in winter, untimely and inadequate repair of equipment operating in severe climatic conditions, and localization of discharges of explosive and toxic compounds into the atmosphere. Other problems include poor supervision of fire safety of residential buildings and entertainment centers.

2.3 Harbingers of Technogenic Emergencies and Ways to Forecast Them

The harbingers of technogenic emergencies are physical phenomena that provide objective evidence of potential hazardous events and processes at industrial facilities and in complex organizational and engineering systems, which can be instrumentally detected and documented for preventive purposes. Since the operation of complex engineering systems requires in the majority of cases different forms of human participation, when considering the signs of approaching disasters in this work we should exclude those that are related to human activities (lack of experience, negligence, mercenary motives or malicious intent that cause a technogenic emergency must be prevented and excluded using legal, juridical, and organizational mechanisms). So the harbingers of technogenic disasters in their entirety can be divided into four groups (Fig. 2.5). Using each alone or in combination makes it possible to forecast an accident in order to take necessary preventive measures.

The first group of harbingers includes failures, breakdowns, and defects caused by both declining reliability of complex man–machine engineering systems and their components. We know from the theory of reliability that there can be gradual failures caused by wear and tear and/or end of service life, which manifest themselves either as abnormal deviations in the work of systems and their breakdown, or as the end of operation due to the depletion of fuel, energy, or other renewable resources.

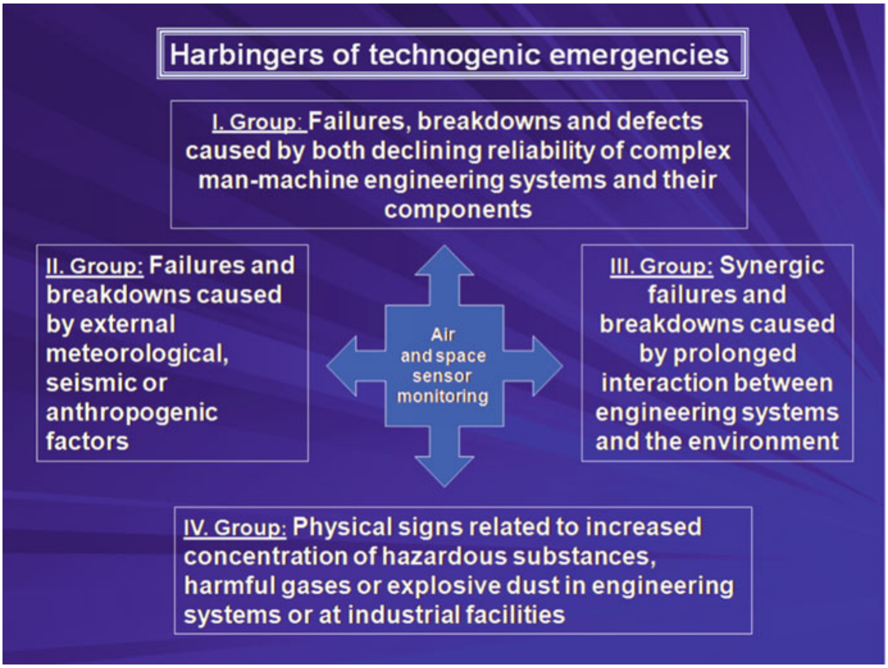


Fig. 2.5 Harbingers of technogenic emergencies

The experience of creating and operating complex engineering systems has allowed mankind to develop and introduce a method for monitoring their reliability and safety. For example, Russian industries have a system of organizational, methodological, and technical regulatory documents (national, industry, and departmental standards, guidelines, and instructions) which enables them to handle effectively increasingly sophisticated and energy-consuming equipment, and ensure its reliable and safe operation.

The second group of harbingers includes failures and breakdowns caused by external meteorological, seismic, or anthropogenic factors. Such technical anomalies occur when external loads exceed the rated ones accepted when designing equipment. Instrumental registration of such anomalies (including accumulation of relevant statistics) along with disaster early warning can help forecast technogenic accidents. It is also important that such monitoring will make it possible to correct (increase) the design parameters of systems.

The third group of harbingers includes so-called synergetic failures and breakdowns caused by long interaction between an engineering system and the environment. For example, many engineering systems, buildings, and installations are operated in seismic or meteorologically aggressive (dangerous) areas. Engineering systems and the environment influence each other in the process of operation and this can lead to an accident or a disaster. For instance, trunk pipelines, railroads, power transmission lines, compressor stations, storage facilities, and urban and industrial infrastructure are located in tropical or permafrost regions that cover big portions of the globe.

Special interest is attracted to the growing number of failures in complex mechanical systems involved in the use of subsoil or other natural resources caused by extreme resonance vibrations due to anthropogenic geodynamic impacts. This causes technogenic earthquakes, landslides, and floods. The harbingers of such failures are geodynamic movements caused by technogenic factors: growing horizontal tectonic stresses, vertical and horizontal displacement of the earth's crust, and other geophysical processes provoked by human activities. They can be detected instrumentally both using contact-type geophysical instruments and remotely.

The fourth group of harbingers includes geophysical signs related to increased concentration of hazardous substances, harmful gases, or explosive dust in engineering systems or at industrial facilities. Such signs can be registered both instrumentally in situ (sensors, gas analyzers) and remotely using mass spectrometers (multi- or hyperspectral ones) and laser tools aboard aerospace monitoring systems.

The use of aerospace monitoring systems (including those for monitoring and troubleshooting purposes) helps detect operational harbingers of technogenic emergencies listed in Groups II and III. The harbingers of Groups I and IV can be effectively detected using ground-based sensors. Data supplied by them through the "space control contour" can be automatically accumulated, processed, and promptly transmitted to the relevant bodies for making decisions regarding safety.

Possible ways to register the harbingers of technogenic accidents in the coal and oil and gas industries are listed below. Accident statistics in Russia's coal industry indicate that, as a rule, accidents are preceded by a number of deviations from the standard production process. For example, it can be growing concentration of methane or carbon dioxide. This necessitates the use of automatic control systems in the return airways of a coal mine or its sections. Modern telecommunication systems can effectively provide such control (and determine microconcentrations of hazardous gases), immediately alerting the personnel on the surface and automatically de-energizing certain equipment, if needed. Telematic systems can already control, without the presence of people, practically all aspects of safe operation of the shearer in the coal mine.

In order to rule out accidents in the Russian oil and gas sector, it is necessary to develop and improve a comprehensive monitoring and diagnostics system for ground-based facilities, especially trunk pipelines, including aerospace methods and means to supplement remote earth sensing information and management systems that already exist in the industry. Russia's Energy Strategy and the Federal Program "Highly Reliable Pipeline Systems" provided for annual comprehensive examination of 20,000–25,000 km of operating trunk pipelines, and for the creation of 100–150 incident prevention and localization units on the existing pipelines. Since major repairs and upgrading costs $120–150 million per 100 km of a large-diameter pipeline, and comprehensive examination and diagnostics requires another $200,000–400,000, it would be advisable to use instrumental control systems more widely, employing modern information and space technologies.

Yamburggazdobycha has positive experience of environmental monitoring at gas production facilities. The company has created a pilot industrial environmental monitoring zone in order to try out and arrange for the use of its main technical means, including:

- Automated systems to monitor hazardous emissions at compressor stations;
- Automated posts to monitor the condition of the air in residential and industrial areas;
- Mobile environmental laboratories to detect the contamination of soil, water (snow), and air in different parts of the Yamburg gas condensate field;
- Systems to monitor the quality of water at water intakes and after cleaning;
- Engineering and geological monitoring equipment to watch the condition of soil under production facilities in permafrost areas; and
- Sets of laboratory and analytical equipment for detailed air, water (snow), and soil analysis.

The above-mentioned means are tied together by an integrated monitoring data transmission network that uses the Yamal satellite system.

For the purpose of monitoring the technical condition of the gas transportation network, the company uses a telemetric system to watch the working parameters of field equipment, pipelines, pumping and compressor stations, storage facilities, etc., an aviation system to respond to emergencies, and a space system to discover new oil and gas fields, and also to monitor the construction and operation of gas pipelines.

Gazprom has lately created and been actively testing a pipeline aerospace monitoring system on the basis of existing and future remote earth sensing spacecraft, as well as unmanned aerial vehicles (Figs. 2.6–2.7).

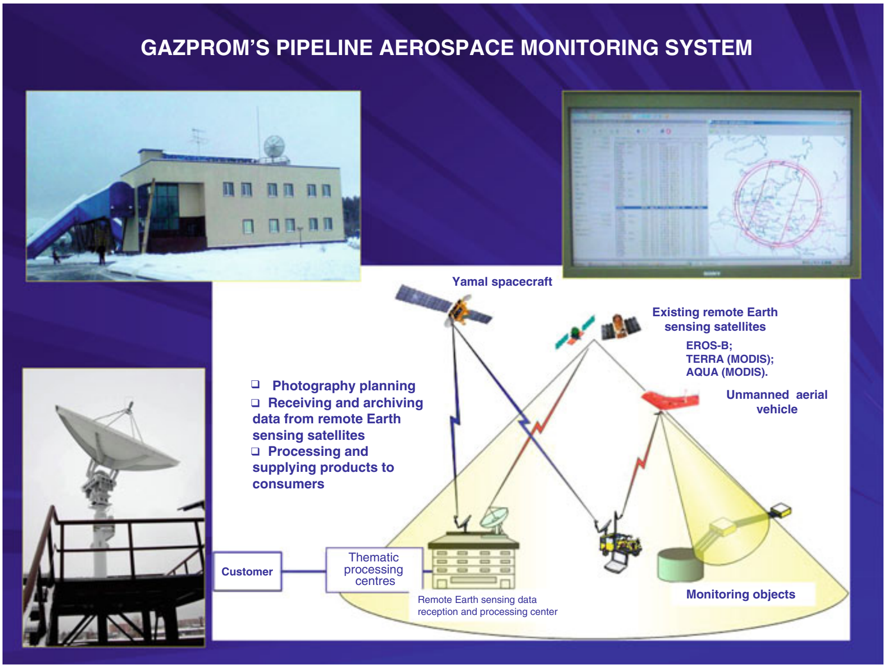


Fig. 2.6 GAZPROM's pipeline aerospace monitoring system (nowadays)

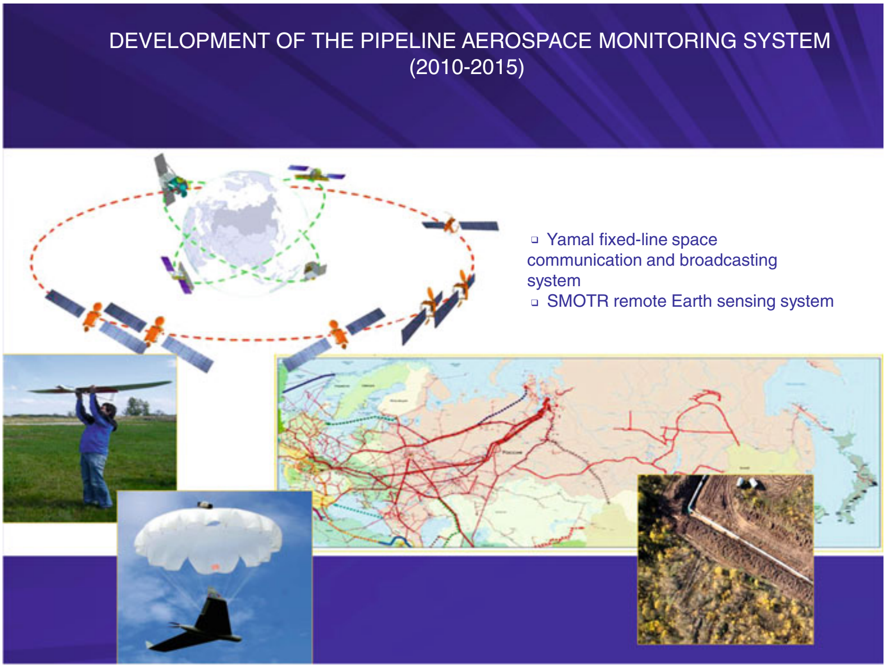


Fig. 2.7 Development of the Pipeline Aerospace Monitoring System (2010–2015)

The system is designed, *inter alia*, to detect sections of trunk gas pipelines laid at a smaller depth than necessary, monitor the condition of gas pipelines, engineering systems and other infrastructure facilities (dykes, surfaced sections, water crossings, transport routes, etc.), watch restricted areas around trunk pipelines and gas distribution stations for unauthorized presence of people and automobiles during the day and at night, illegal construction or logging operations, and oversee construction works and relocation of construction machinery and equipment.

2.4 Geodynamics, Seismic Location, and Prospects for Forecasting Technogenic Emergencies

The transformation of the theory of mobility of the earth's crust should probably be linked to A. Wegener's hypothesis of continental drift which appeared in the early twentieth century and became a theory of plate tectonics in the second half of the last century [3]. The onset of satellite technology in geodetic surveying made it possible to determine the numerical values of these displacements experimentally. Large-scale experimental studies at geodynamic testing ranges exposed intensive local anomalies in vertical and horizontal displacements of the earth's crust linked to crust fractures [4], which have a big amplitude (up to 50–70 mm/year) and are brief (0.1–1 year), localized in space (0.1–1 km), pulsing and alternating. The use of differential GPS technologies for periodic (discrete) and continuous monitoring of trend and vibrational displacements and deformations helped identify a new class of geodynamic movements in fractured areas with a period of 30–60 s and 40–60 min, and confirmed movements occurring at intervals up to 1 year and more [5]. Places with geodynamic movements tend to gravitate toward active tectonic structures and adjacent rocks.

Current geodynamic phenomena include trend and periodic, cyclic movements of rocks in the upper layer of the earth's crust, each of which creates its own specific patterns for the development of accidents (sagging, collapse, destruction of headers and water supply lines, etc.). But trend and vibrational geodynamic displacements affect technogenic objects differently. Trend displacements place an extra stress on the structure of facilities due to slow dislocations and deformations in rock mass. Therefore, facilities located in an area of active tectonic structures with strongly marked trend movements begin to fall apart when the stress within them reaches maximum levels. However, such structures occur rarely, even though trend movements can be initiated by technogenic activities as well. The results of geodynamic studies conducted in recent years and illustrating this method are contained in Table 2.10.

During cyclic geodynamic movements, the process develops in two ways: cyclic deformations and displacements affect a facility directly or in a combined manner, the latter being a result, among other things, of changes in the property of the rock interacting with the target object. In the event of cyclic movements, there can be several reasons for disintegration of technogenic facilities: during direct impact, a facility can be destroyed either by excessive stress and deformation, or by internal

Table 2.10 Some results of geodynamic movement studies for technogenic facilities

Target object	Type of monitoring	Maximum displacement, mm		Maximum deformation, $1 \cdot 10^{-3}$	
		Horizontal	Vertical	Horizontal	Vertical
Surgut, oil pipeline	Continuous	47	108	1.17	2.69
Surgut, sewage system	Continuous	57	92	1.03	1.46
Sarana, radio relay tower	Periodic	48	28	—	—
Kamensk-Uralsky, dolines	Continuous	8	22	0.08	0.37
Yemanzhilinsk, Bukhara-Urals gas pipeline	Continuous	38	63	0.18	0.17
Yasny, Kiyembayevsky open-cut mine	Periodic	335	113	0.06	0.04
Zheleznogorsk-Ilimsky, Korzhunovsky open-cut mine	Periodic	629	600	1.20	0.29
Beloyarsk NPP, Unit No. 4	Continuous	5	5	0.10	0.10
Khromtau, Donskoi ore dressing factory	Continuous	15	31	0.09	0.22

fatigue. During combined impact, destruction can occur because of excessive stress caused by three factors: a change in the property of the rock mass, the combined impact of cyclic movements and thixotropy, or internal fatigue in a facility caused by the same factors.

Cyclic movements of the earth's crust occur more often and can have a variety of effects ranging from the direct impact of cyclic deformations on a facility to that produced by a change in the property of the rock mass in the areas of crustal fractures due to alternating stresses. The pattern of direct impact of cyclic movements on engineering systems is quite simple: if the amplitude of alternating deformations exceeds the maximum stability levels designed for structural parts of a facility, this will cause structural failures resulting in an accident. If deformation is below the maximum permissible level, an accident may or may not occur depending on fatigue in the structural parts of a facility.

Of the short-lasting geodynamic vibrations, the most dangerous are those that last around 1 min or approximately 1 h and create annually 500 and 9,000 stresses, respectively. The period of time during which facilities are destroyed by such vibrations depends on the amplitude of alternating deformations as against their maximum levels. For example, corrosion increases cyclic stresses on the metal parts of pipelines tens and even hundreds of times.

A rather commonly occurring phenomenon characterizing alternating cyclic stresses is the changing property of the rock mass in the areas of crustal fractures induced by such stresses. However, its external signs are not vivid and it is hard to determine their impact on technogenic objects. This phenomenon was for the first time described in the works of the Research and Technical Firm "Geofizprognoz" after studying crustal fracture zones using the profile shooting method [6]. It was determined in particular that cyclic stresses in crustal fracture zones create areas with substantial deviations in strength and deformation properties of the rock mass. It was assumed that the rock mass in a crustal fracture zone is in thixotropic state. This helped solve numerous practical tasks such as determining the nature and patterns of a number of technogenic accidents and disasters (including an accident in St. Petersburg's subway system).

Thixotropy is known to occur in a number of soils and rocks during earthquakes. Alternating cyclic stresses cause them (while having considerable bearing power in static condition) to soften and lose a great deal of their strength, which often results in the tilting and collapse of dwelling houses and other engineering systems. However, this phenomenon occurs only briefly during an earthquake and soil regains its strength after the end of the tremors. Thixotropy in crustal fracture zones, which in many cases consist of rock with a more deformed structure, occurs implicitly for long periods of time and possibly even continuously in historical terms. This phenomenon can be described more precisely by the term "quasi thixotropy." It is believed that the quasi-thixotropic condition of rock in a crustal fracture zone is caused by alternating cyclic displacements, when induced stresses change their strength and deformation properties. Depending on the design features of installations that interact with the rock in a crustal fracture zone, different patterns and scenarios of emergencies can evolve.

For example, the north-western wall of the main open-cut mine at the Korshunovsky ore dressing factory (Urals) has been in critical condition for more than 35 years in a section crossed by a 500-meter latitudinal fracture. Big landslides with the slope angle of 22° have been occurring in the mine since 1975, even though its underlying sedimentary rocks were estimated to remain stable at bigger angles of 28–30°. The movement of surveying posts placed along the perimeter of the mine has been monitored annually to expose their cyclic displacement. The transformation of the rock mass is considered to be a transition to thixotropic state. For example, the mine has a water gallery that draws off the local river from the production area. An examination of the gallery showed that the monolithic reinforced concrete lining in the crustal fracture zone is divided by ring fractures into 7–10-meter sections through which underground water seeps into the gallery, sometimes even spurting under pressure. However, the fractures have practically never occurred in the construction joints in the lining. Therefore, an emergency at the Korshunovsky open-cut mine is developing mainly due to active geodynamic processes in the crustal fracture zone, which requires constant monitoring in order to prevent irreversible destruction.

Intensified karstification is one of the factors that provoke technogenic emergencies. Russian scientists encountered this phenomenon when studying the causes of increased karstification in the residential area of the city of Kamensk-Uralsk and in one of the sections of the Bukhara-Urals gas pipeline near the city of Yemanzhelinsk (see Table 2.9). Dolines appeared to have been caused by alternating stresses in the rocks and their transition into quasi-thixotropic state that had intensified erosion. A series of sinkholes in the crustal fracture zone that crosses the gas pipeline route had resulted in the exposure of its third section, creating a serious technogenic danger.

The above-mentioned examples illustrating the risk of technogenic accidents and disasters suggest the following schematic interconnection between them and contemporary geodynamic processes (Fig. 2.8). For example, a big group of technogenic accidents is caused by both direct and indirect impact of geodynamic processes on technogenic facilities.

Geodynamic phenomena in the earth's crust occur naturally due to tectonic processes, or are caused by anthropogenic activities. The geodynamic crustal patterns that manifest themselves through crustal deformations are the same. The difference is in scale and physics. For example, some studies indicate that the area of geodynamic processes caused by the operation of a big mining enterprise can have a radius of several dozen kilometers [7].

Slow deformations, as a rule, are not accompanied by seismic effects, and devastating consequences are limited either to the foundation of a facility or the facility itself if it is of an underground (semi-buried) type. However, despite the absence of seismic effects, the danger of such deformations is characterized by relatively high rates of changes in the earth's crust that can reach $3{\bullet}10^{-3}$ m a year even in seismically quiet regions of the Urals. This happened in 1961–1962 in two districts of Sverdlovsk region where 0.4-km-wide-open fissures had developed [8].

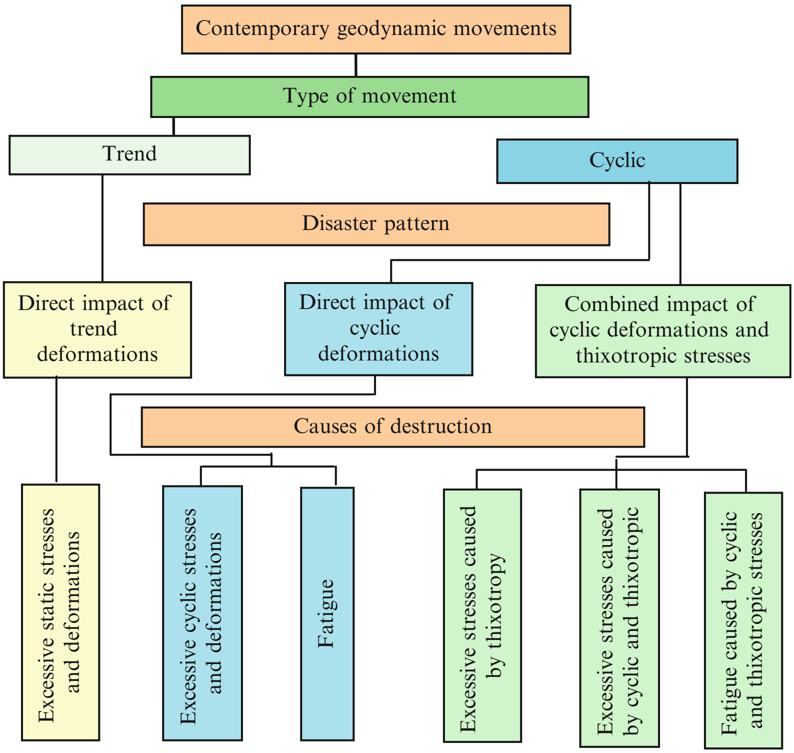


Fig. 2.8 Interdependency between technogenic accidents and geodynamic processes

The observable spread of areas of slow deformations and crustal movements poses a real threat to vital and environmentally vulnerable technical facilities. Such zones occurring in places of crustal fractures are likely to cross extended technical facilities such as trunk pipelines, railroads, power transmission lines, etc., as well as protective dams on water reservoirs, and mining sites.

Theoretical studies of large-scale technogenic effects on a given section of the lithosphere are based on classical solutions of flow mechanics. Experimental studies of deformation caused by man-made effects of mining operations are conducted by way of monitoring survey markers installed at the mining sites. Given the size of such sites, such monitoring became effectively possible only after the use of GPS geodetic devices for research purposes.

It is common knowledge that the Urals is the biggest and the oldest mining region in Russia and the risk of technogenic accidents caused by intensive mining operations is quite real there. For example, the three biggest open-cut mines in the Urals which produce iron ore (Kachkanar), asbestos (Asbest), and coal (Korkino) have already exceeded the permissible level of technogenic impact beyond which induced geodynamic processes begin. A similar situation can be seen in the areas of underground production of salt (Solimkamsk), bauxites (Severouralsk and Satka), and iron ore (Kushva, Nizhny Tagil). Specialists name at least seven mining areas that are potentially dangerous in terms of induced geodynamic processes. Such processes, including earthquakes with a magnitude of M = 4–6, have already occurred in some of them.

The Mining Institute of the Urals Branch of the Russian Academy of Sciences has extensive instrumental monitoring data concerning the movement of rocks at the mining enterprises in the Urals over more than 30 years. Satellite surveying technologies open up utterly new opportunities in this field. The institute has created the Urals Center for Geomechanical Studies of the Nature of Technogenic Accidents in the Mining Areas, which has GPS surveying equipment that can monitor crustal deformations caused by the technogenic impact of mining operations. The Center's laboratory studies of plate models and analytical calculations based on the theory of shells indicate that natural horizontal tectonic stresses in the crust (the first invariant of which is estimated at 30.8 MPa on average [9]) create a certain critical load that can cause a deformation. This form of buckling distinguished in the theory of shells causes immediate deformations and seismic effects. Technogenic loads in this case act as a trigger that determines the time and the place of such occurrences.

One of the characteristic zones of large-scale technogenic impacts is the asbestos production area (Fig. 2.9) in the Urals. The depth of open-cut mines from which more than five billion tons of rock have been taken and moved mainly to refuse dumps has reached 300 m. In addition to the open-cut mines and refuse dumps belonging to Uralasbest Plant, there are also other technogenic factors such as the Kurmanovsky chipping quarry and the Malysheva emerald open-cut mine, as well as the Reftinsky and Beloyarsky water reservoirs, each with a capacity of about 1 km^3. The risk of geodynamic processes is exacerbated by the presence of the Beloyarsky nuclear power plant in the area. Because of the direct risk of

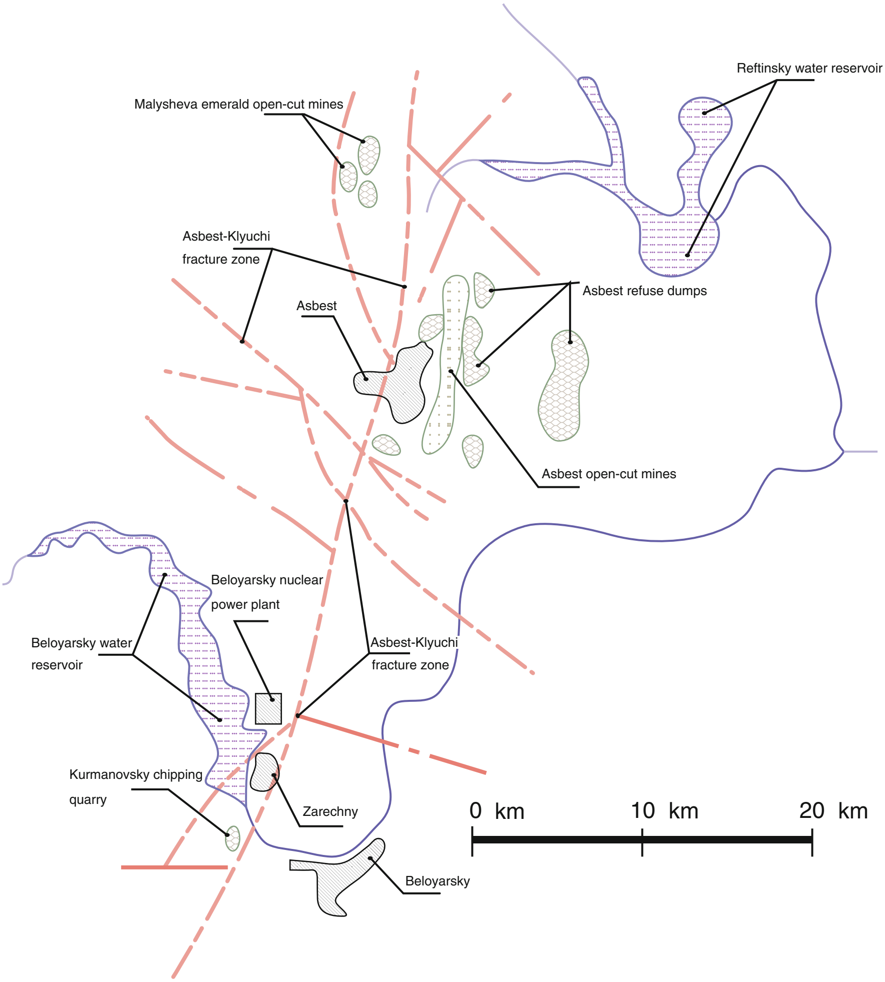


Fig. 2.9 Area of large-scale technogenic impact on the earth's crust (Asbest, Urals)

anthropogenic seismic processes in this part of Russia, scientists from the Urals Center for Geomechanical Studies have made some forecasts.

Theoretical studies using the geomechanical model of the area with a given technogenic impact level (Fig. 2.10) show that vertical crustal displacements have obvious areas of oppositely directed deformations – areas where the crust is rising due to the technogenic impact of mining operations and areas where the crust is sagging due to the loads created by refuse dumps and water reservoirs. The uplift and subsidence rates are almost identical and reach 1 m.

The results above were obtained on the basis of theoretical solutions in which the model environment (the structure of the rock mass) was assumed to be homogeneous. In a real hierarchic environment of a block, deformations are discrete.

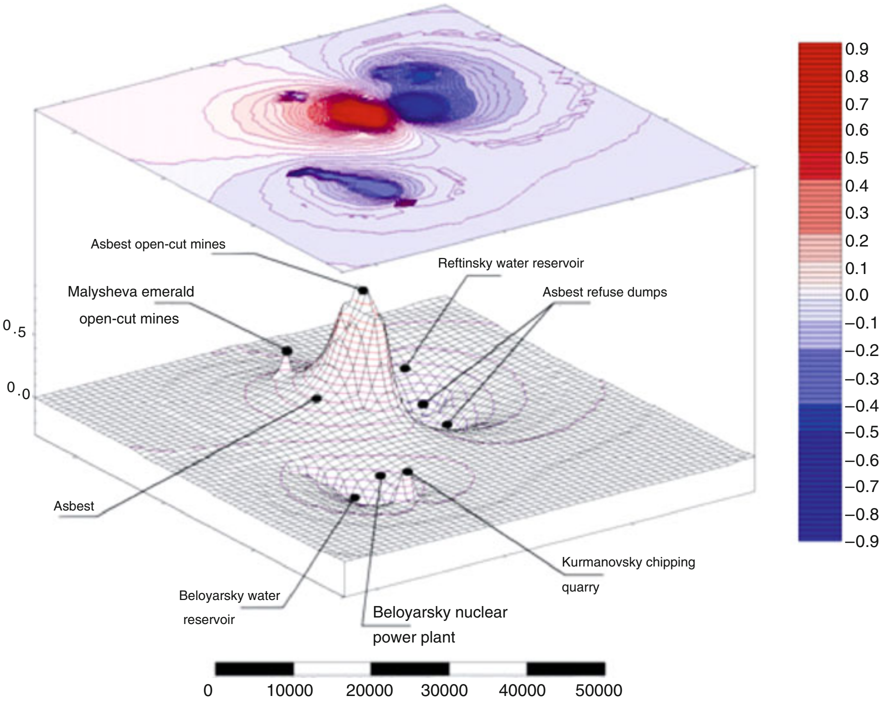


Fig. 2.10 Geo-mechanical model of large-scale technogenic impact on the earth's crust (Asbest, Urals)

This requires serious corrections to be made in projections. Nevertheless, the obtained results showed that the level of vertical displacements of the crust due to technogenic factors is comparable with the levels registered in regions of major earthquakes, and the closeness of technogenic loads opposite in sign creates areas with a high vertical displacement gradient, tremendously increasing the risk of geodynamic seismic effects in such zones.

So, stresses and deformations in large sections of the earth's crust change considerably due to long-term mining operations, which can cause geodynamic processes and disastrous consequences. Therefore, the study of deformation patterns in the upper layers of the lithosphere caused by long-term mining operations becomes particularly relevant. The forecasting of technogenic disasters, their dynamics and prevention requires geodetic monitoring using satellite surveying and aerospace surveillance technologies.

The interconnection between contemporary geodynamic processes and the yet-to-be-discovered mechanisms of technogenic disasters in the mining industry provides a theoretical basis for determining a strategy for fundamental studies related to forecasting anthropogenic emergencies. In the future, this can help solve more effectively a number of applied tasks aimed at preventing such emergencies and reducing their negative effects.

Scientific results achieved in the field of seismic location and spectral seismic surveying can be of interest in this respect. It is known that so-called “areas of tectonic faulting” in the lithosphere are often blamed for different technogenic disasters, such as sudden collapses of buildings and installations, road cave-ins, pipeline bursts, rail ruptures, etc. By detecting these zones, it is possible to forecast technogenic accidents and disasters (this is what geological engineering was created for).

Studying and mapping areas of tectonic faulting have become possible with the development of the spectral seismic survey profiling method [10], which can detect such areas through increased values of the Q-factor in the harmonic components of the seismic signal. It is known [11] that the notion of the Q-factor can be applied only to decaying harmonic signals. A signal can be either harmonic or generated by interference of nonharmonic components. If it does not contain a decaying harmonic process, i.e., it was generated by interference, its Q-factor equals 1. The slower a decaying harmonic signal fades out, the bigger its Q-factor is. Conversely, the longer (slower) a harmonic signal fades out, the more destructive its consequences are. The Q-factor describes both the decaying harmonic signal and the vibrating system that generated it (if there is a signal with a Q-factor, the vibrating system that generated it has the same factor).

It is known that resonance is a coincidence of the frequency of periodic external impact with the frequency of the vibrating system that is experiencing such impact. Such interaction generates a gradual, from period to period, increase in the amplitude of vibrations. The amplitude can increase Q times. Real values of the Q-factor in areas of tectonic faulting range between 50 and 100, but the growth of vibration amplitude is restricted by elastic deformation limits and the ensuing accident. Usually, destruction takes place before the maximum amplitude has been reached, and it occurs instantaneously as if struck. This phenomenon is well known and is called a mine shock or a technogenic earthquake.

The safety of many engineering systems is assessed in terms of resistance to resonances. Bridges are known to have collapsed under marching troops due to resonance when the frequency of the rhythmically stepping people coincided with the own frequency of the bridge’s elements as vibrating systems with a high Q factor. However, the possibility of resonance in the “engineering system – earth strata as a foothold” has never been considered. Many technogenic disasters have never got explanation due to this reason. For example, accidents at facilities that have vibrational impact on soil (different power plants, pumping stations, etc.). Entering into resonance is a transitional process that can be caused by a change in the work of a vibrating object, such as a change in the frequency of vibration due to a higher or lower generator speed (as was the case at the Chernobyl nuclear power plant) or the passage of a train at a certain speed through an area of tectonic faulting [12]. This category of technogenic accidents can be effectively forecasted using the spectral seismic profiling method based on seismic location. So, with time, after resonance phenomena have been better studied, it will be possible to avoid technogenic accidents similar to those described above.

But another cause of destruction – planetary pulsation – is much more troublesome for engineering systems. Some of its manifestations are known. For example, it causes significant surveying errors in certain places. Planetary pulsation occurs exclusively in areas of tectonic faulting [8] and has a rather small frequency (tenths and hundredth of a Hertz). The amplitude of such vibrations can reach 10 cm, but it is not constant and can dwindle to zero from time to time. The vector of an alternating shift in the pulsing surface changes with time both in value and direction. The frequency of pulsation changes as well.

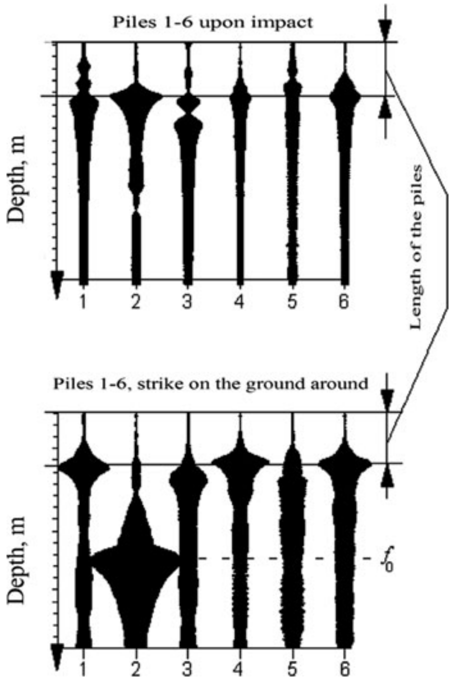
Planetary pulsation by itself causes engineering systems to collapse. This can be easily understood if one imagines that one part of the foundation under an installation stands on stable soil, while the other part, being located in an area of tectonic faulting, starts swaying. Naturally, neither a reinforced concrete nor even metal (pipelines, railway tracks, etc.) construction can withstand such loads, even though the latter can, unlike the former, absorb bending stresses. The generally accepted point of view is that the stronger the foundation, the safer the engineering system is. However, practical experience indicates that the strengthening of the foundation does not always increase safety, especially if the foundation is designed without taking into account planetary pulsation (it’s like a young flexible tree that can survive a storm that can break an old and unbending one). A break in reinforced concrete plates in the so-called “floating base” caused the collapse of the water park in Moscow’s Yasenevo district, killing and injuring dozens of people.

The impact of planetary pulsation on certain vertical constructions (posts, supports, etc.) causes them to incline toward the center of the stress zone (this explains why posts and trees tilt in the same direction). As a rule, the objects that tilt are located on the fringe of the zone, while those in its center sway. Clearly, if vertical posts holding a pyramidal roof sway, the risk of its collapse increases. Pulsation causes piles driven into the ground to sway in much the same way. If they are built into the foundation frame or floating base, either a pile itself will break at the place of attachment or the construction to which it is affixed will fall apart. When planetary pulsation increases, the number of such incidents increases too. This happened in the winter of 2005–2006 when the roofs of several reinforced concrete buildings in Russia, the Czech Republic, Switzerland, and Germany collapsed at the same time.

The sudden collapse of pumping stations standing on piles built into a floating base occurs quite frequently in the Russian oil and gas industry. After studying the construction of the piled foundation at one of the enterprises in Surgut, experts came to a paradoxical conclusion: the use of the most up-to-date technologies and materials does not make a building stronger and may even increase the risk of its subsequent collapse if vibratory properties of the lithosphere are not taken into account.

An observation of piling operations showed that it takes dozens of times fewer strikes (!) to drive some of the piles into the ground, suggesting lesser friction between a pile and the soil, which usually happens in tectonic stress zones due to the highly loose rock mass that makes up the upper layer of the lithosphere. Figure 2.11 shows the results of measuring the rate of friction between piles and the ground, using the spectral seismic surveying method. What makes these

Fig. 2.11 Study of friction between piles and soil using spectral seismic surveying method



measurements distinct is that six piles driven into the ground and standing next to each other were examined twice: the first time, when the pile was struck and the second time when the soil around it was struck (in both cases, a seismic receiver was affixed to a pile).

A common feature shown by all piles was that their length on the ultrasonic image was not very clear with the exception of pile No. 2, the size of which upon impact appeared to be much clearer than that of the other piles, but it did not register at all when the ground around it was struck. This can be explained by lesser friction between pile No. 2 and the soil when, on the one hand, its own lengthwise vibrations are not dampened, and, on the other hand, there is a reduced acoustic contact with the ground. There was yet another interesting effect: when the ground was struck, the above-mentioned harmonic vibration process with a colossal Q factor was registered at a certain frequency f_0.

Although it is not quite clear what exactly generated this vibration process in the "pile–soil" system, such a vibrating system with a high Q factor is the reason for the resonance with the vibration object, for which the foundation was essentially built, and the cause of a mine shock. This leads to explosion-like and instantaneous destruction of the foundation as in the case of gas pumping stations.

Sometimes, it takes a very small number of strikes to drive a pile into the ground. It is also believed that it can't hurt if a certain number of piles simply hang upon the plate rather than hold it. However, such hanging piles will sway to break loose of the plate, and if there are many of them, the plate can simply snap. So, if a facility with vibrating devices is built in an area of tectonic stress, there are two factors causing the plate to snap: vibration and planetary pulsation. If a facility happens to be in a hazardous zone, a piled foundation with a floating base runs a greater risk of sudden collapse than when a floating base and piles are not used at all.

Therefore, there are two types of alternating impact on the lithosphere: vibration from working mechanisms and planetary pulsation. The former, being a higher frequency one, can cause resonance with the own frequencies of adjacent rocks, while the latter, as a low frequency one, can cause resonance with the underlying structures (for example, the pulsation frequency of 1 Hz corresponds to a 2.5-kilometer stratum, and a frequency of 0.1 Hz corresponds to a 25-kilometer stratum). If the frequency of planetary pulsation is close to the own frequency of the lithosphere structure, and if its Q factor as a vibrating system is big enough, the risk of resonance phenomena, i.e., earthquakes, increases immensely.

The pattern of a natural earthquake differs from that of a technogenic one. It happens even if the frequency of planetary pulsation changes and nears the frequency of resonance. The amplitude of soil vibrations increases, as has been registered by seismologists immediately before an earthquake. If the frequency of planetary pulsation does not coincide with the own frequency of the relevant vibrating system but is close to it, so-called beats occur.

The earth's crust in areas of tectonic faulting appears to be quite mobile and using it without taking this factor into account increases the frequency of technogenic accidents, and the oftener the ground comes under static or dynamic impact, the more intensive they will be. A transition to the perception of earth strata as a combination of vibrating systems both in the general methodological and purely practical terms is as important as is the transition from geocentric to heliocentric views, and helps to make the operation of engineering and technical systems safer. Such a change of paradigm will make it possible to reduce considerably the number of technogenic accidents, rule out technogenic seismic processes and effectively forecast natural earthquakes.

2.5 Forecasting of Man-Made Disasters and the Role of Space Systems in its Practical Implementation

Natural and technogenic processes often have close and sometimes paragenetic connection. But while natural calamities, especially of space and endogenous nature, can in principle be forecasted but cannot be practically prevented, technogenic accidents and disasters can be both forecasted and prevented. Much or everything depends on the will and the quality of work, the comprehensiveness and promptness of monitoring systems (both ground-based and aerospace systems), and means of protection for personnel, constructions, and facilities. There is a tendency to move from fundamental studies focusing on the physical nature of the environment and space and time changes in it to forecasting and preventing natural and technogenic disasters.

Scientists say that deterministic approaches have no fundamental physical basis for offering clear short-term forecasting criteria. Statistical probability methods of forecasting do not always justify themselves, apparently because of fundamental aspects of the transient and heterogeneous nature of space and time, and the unclear quantitative role of each of these factors in the probability of certain devastating processes. The search for evidence as well as necessary and sufficient conditions for natural and technogenic disasters and the optimal number of measureable factors is one of the vital aspects of further work.

The current state and dynamics of space and geosphere, as has been repeatedly pointed out, is largely assessed as critical not only because of the natural processes inside the planet and in the surrounding physical space, but also because of the scale of human interference in the physical and ecological state of the earth. So not only do natural processes and their dynamics cause technogenic accidents and disasters, but technogenic processes themselves bring about such changes in the natural state of the planet that eventually produce catastrophic impact on industry and society.

Dangerous exogenous and endogenous processes coupled with the lack or absence of protective measures or facilities, imperfect technologies and natural aging of infrastructure, incompetence or temporary inability of the servicing personnel can cause considerable financial losses and socio-economic damage. This warrants further efforts to explore ways for forecasting interaction between dynamically changing properties of infrastructure and continuously changing geological environment, taking into account external factors. In so doing, it is necessary to use both contact-type and remote sensing methods. For example, one of the key current processes is the growing capacity of permanently operating units and facilities, as a result of which technogenic vibration and noise already exceed the planet's maximum natural micro seismic background level by one order or two orders of magnitude, and change the engineering, geological, and seismic parameters of hitherto "quiet" places. Stresses exceeding the endurance strength of materials build up as a result of long-term operation of such facilities. Failures and breakdowns caused by wear and tear, and end of service life can be forecasted using statistical probability methods. Changes in the environment are studied using geophysical methods.

Summing up the aforesaid, we should emphasize the diversity of factors that cause technogenic accidents which require unique analysis and forecasting methods, as well as contact-type and remote prevention techniques. Man-made emergencies caused by wear and tear, end of service life, technogenic effects on the geodynamic environment, increased concentrations of hazardous and explosive substances, gases and dust can be forecasted using physical and mathematical modeling. For example, continuous mathematical monitoring of potentially hazardous facilities using a dynamic model of safe operation has been proposed [13].

Aerospace monitoring facilities have certain capabilities to detect, forecast, and prevent technogenic processes, even though the majority of them (see above) have no reliable harbingers that could be registered by aerospace systems, with the exception of anthropogenic disasters caused (provoked) by:

- Geological and meteorological calamities;

- Extreme resonance processes in mechanical systems caused by geodynamic vibrations in the earth's crust;
- Increased concentrations of potentially hazardous gases and/or dust;
- Cascading failures of geotechnical systems (trunk pipelines, railroads, etc.) as a result of interaction with the environment;
- Use of equipment for unusual purposes associated with gross violations of technical system operating rules.

Aerospace monitoring provides a tool for early detection and prevention of destructive processes in geotechnical systems, oil spills and gas leaks, siphoning of petrol products, etc., for mapping areas intended for the construction of large technical facilities and monitoring their construction in order to detect erroneous or intentional deviations (in pipeline routes, in the construction of power transmission lines, railroads, etc.); for geodetic and environmental monitoring, and early warning of emergencies (fires, gas outbursts, hazardous spills, etc.).

The Federal Agency for Mining and Industrial Supervision (ROSGORTECH NADZOR), the Russian Federal Inspectorate for Nuclear and Radiation Safety (ROSATOMNADZOR), and the relevant bodies within federal executive agencies monitor the state of industrial facilities and forecast possible accidents at them. Similar bodies exist at the regional level as well as within enterprises and organizations, and are known as industrial safety units. Monitoring is conducted using ground-based and aerospace systems of the relevant ministries, agencies, regional authorities, and organizations (enterprises) depending on their jurisdiction. The main element of the system is ground-based sensor monitoring networks and laboratory control capabilities of the federal civil defense organizations and its key elements subordinated to the Federal Agency for Hydrometeorology and Environment Monitoring, the Emergencies Ministry, the Agriculture Ministry, the Ministry of Health and Social Development, and the Ministry of Natural Resources.

Russian space-based monitoring means are currently used mainly for detecting and specifying slowly evolving large-scale natural phenomena and processes. Aviation capabilities are used for the same purpose, as well as for monitoring the state of trunk pipelines, radiation, road, snow, and ice in areas of extensive destruction, etc. They have broad possibilities both in terms of coverage and promptness of information delivery, which makes them useful for a number of monitoring services that operate within their respective jurisdictions.

General operational terms of Russia's national forecasting and monitoring system are set forth in Regulation on the System of Monitoring, Laboratory Inspection and Forecasting of Natural and Technogenic Emergencies No. 483 of the Ministry for Emergency Situations of November 12, 2001, and in the regulations of its units and elements, in the regulatory documents of the relevant federal ministries and agencies, regional and territorial authorities. The results of emergency monitoring and forecasting serve as the starting point in developing long-term, medium-term, and short-term target programs and plans, and in making relevant decisions to prevent and respond to disasters, including technogenic ones.

The Russian Federal Space Program calls for developing national remote earth sensing system up to 2015, including the creation and/or development of certain space assets that can jointly monitor natural calamities and technogenic disasters. These include remote sensing and monitoring, navigation and hydrometeorology, communications and relay systems. All of these space systems should, despite of their departmental disunity, constantly interact with each other through ground-based infrastructure designed for controlling space missions and for receiving, processing, and distributing space data. A combination of these space systems should be a multilevel hierarchic and constantly evolving intellectualized structure. Its ground-based elements should include centers for controlling space missions and for receiving, processing, and distributing space data, centers for thematic processing of monitoring data and developing methods of decoding and identifying observable processes and objects, an aviation surveillance system, test ranges for validating space data and grading onboard equipment used for monitoring natural and technogenic objects and processes, and situation centers for analyzing and gathering monitoring information as well as ground-based telemetric data necessary for making operational and strategic decisions.

Although Russia has launched only two remote earth sensing satellites – medium-resolution “Monitor-E” and ultra-high-resolution “Resurs-DK1” – in the past several years, new space optical and electronic monitoring satellites “Resurs-P” and “Arkon-Viktoria,” radar observation satellites “Arkon-2” and “Kondor-E,” a space system based on “Ekola” mini satellites, the above-mentioned “Smotr” gas industry monitoring system, the Arctic subpolar observation system, and other systems are expected to become operational by 2015 with the help of off-budget funding.

Many projects related to building of environment and/or hazardous facility monitoring space systems have been published in the world lately, but they have no clearly defined prognostication value. The analysis of such projects (see details in Chap. 3) showed that effective monitoring of technogenic facilities would require a space system incorporating a wide range of observation means, such as ultraviolet, visible, and infrared optical and electronic equipment (multispectral and hyperspectral), multichannel microwave equipment, multifrequency radar equipment (in the super-high and ultra-high frequency band), laser and lidar multifrequency equipment, as well as powerful onboard information systems with a memory of hundreds of gigabytes. Given the current level of technology, its combined weight will be no less than two tons. A satellite furnished with such equipment could weigh about ten tons, and its power consumption would exceed 10 kV (the ENVISAT satellite weighing about eight tons and carrying only some of the above-mentioned equipment weighing 1,200 kg could serve as an example of such a solution). In order to ensure hourly information updating, it would be necessary to have six to twelve satellites in such an orbiting system, the cost of creating, testing, and deployment of which would amount to billions of U.S. dollars, let alone the creation of ground-based infrastructure, which would take at least 10–12 years. Such a program can hardly be implemented by any, even the most industrialized, nation alone.

A different approach is used now: space systems are created for big groups of similar tasks facing different customers and information users. Therefore, technogenic disaster monitoring can also be conducted using various space systems.

For example, there is a large remote earth sensing orbiting system consisting of dozens of optical and radio monitoring satellites, including military and dual-purpose ones. Most of them can perform not only civilian monitoring and mapping but also surveillance and target-marking functions during armed conflicts (the U.S. and NATO use both their own civilian high-resolution remote earth sensing satellites and similar systems owned by European countries, Israel, India, Japan, Canada, and others, thus conducting almost continuous monitoring of conflict zones, planning combat operations, and using high-precision weapons). It is possible that similar policy can be applied during periods of increased natural and/or techno risks, with the use of military (dual-purpose) space systems for monitoring of natural disasters and emergencies.

Weather satellites which perform global climate and weather monitoring functions make it possible to forecast and warn of natural disasters caused by atmospheric disturbances: storms, floods, cyclones, torrential rains, droughts, etc., which often cause transport accidents on land and at sea. Weather satellite constellations are located on two levels. The upper echelon of such systems is located in geostationary orbit and forms an integral part of the global monitoring system under the World Meteorological Organization. The number of satellites in geostationary orbit should be sufficient for conducting continuous Earth monitoring in an area stretching from 70° North latitude to 70° South latitude and for downloading fresh weather data updated every 30 min or more frequently. This used to be achieved effectively by a system of five geostationary satellites: two American, one European, one Russian, and one Japanese. In 2007, this orbital constellation consisted of the following satellites: a U.S. satellite (GOES), a Japanese satellite (MTSAT-IR), two Indian satellites (Metsat-1, Insat-3A), and one Chinese satellite (FY-3 C). The lower echelon of weather satellites is deployed at low geosynchronous subpolar orbits for the monitoring of the earth's cloud cover and other weather phenomena; measuring vertical atmospheric temperature and humidity profiles and sea surface temperature, surface wind, ice and snow cover; and gathering information from environmental geophysical monitoring platforms, etc. The low-orbit echelon currently consists of national weather satellites: NOAA-K, DMSP 5D-3 (U.S.), Metop (Western Europe), FY-1D, FY-3 (China), and Meteor-M (Russia).

The availability and broad capabilities of the domestic and foreign navigation systems (GLONASS, GPS, and GALILEO) make it possible to promptly position mobile objects and solve space surveying tasks as part of geodynamic studies and for the purpose of monitoring dangerous natural and technogenic objects.

Space communications and relaying system becomes increasingly important. There are dozens of communications and data transmission satellites owned by the U.S., Russia, China, India, Japan, Italy, and another 16 countries and currently operating in geostationary orbit.

Therefore, the space infrastructure needed for monitoring of natural and technogenic disasters is already in place. It is only necessary to focus on creating a system of satellites carrying special equipment that is not available in traditional monitoring spacecraft. Such equipment can be made and put into orbit aboard small microsatellites and multipurpose orbiting platforms that alongside other monitoring, communications, and navigation systems could effectively solve monitoring and forecasting tasks for the benefit of all interested parties using integrated international information, navigational and telecommunication capabilities. The fourth chapter in this book explores a possible design for such a system – the International Global Aerospace Monitoring System (IGMASS).

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