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ANTHOLOGY OF DISASTER AT JAPANESE NUCLEAR POWER PLANT FUKUSHIMA-1

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The extensive material about the origin and deepening up to turning into a disaster and the elimination of an emergency at the nuclear power plant Fukushima-1 is systematized and generalized based on the analysis of public government data and results of scientific researches. The events that have resulted in the destruction of buildings and structures, loss of life, evacuation of the population from the zone of radioactive contamination are presented chronologically. The article demonstrates the large scale and complexity of problems existing in the field of ensuring the nuclear and radiation safety of the population. The ways to minimize the risk of accidents and reduce the risk of negative impacts on the environment and public health are described. The ideas about the different approaches of the countries of the world to the prospects of the nuclear power development taking into account the consequences of the accident at the nuclear power plant Fukushima-1 are specified. The comparative characteristics of different types of technical solutions in terms of safety are provided.

Key words: nuclear power engineering industry, nuclear power plant, radiation accident, emergency situation, radioactive contamination, radiation safety, health risks.

The disaster at Japanese NPP Fukushima-1 in March 2011 is the largest radiation accident in the world after Chernobyl NPP. The understanding of the reasons of accident and the scale of the consequences of this disaster allows for obtaining the useful lessons for future and develop the weighed relation to the further development of nuclear power engineering industry, taking into account for the life and health of people.

It should be noted that Japan, in contrast to USSR and Russia, which completely disclosed the causes, safety measures and forecast of consequences of Chernobyl disaster, extremely unwillingly shares the information about this disaster [16, 24]. The governmental report of Japan does not contain the description of necessary details for complete understanding (both for specialists and non-specialists in the field of designing and operation of such NPPs) of the occurred processes.

The nuclear power engineering industry gained a priority since 1973. In 2010 the country used 54

units of nuclear stations manufacturing 46823 MW (e), constructed 2 more units with capacity of 2650 MW, in total it planned to build 14 units. 30% of power needs was covered at the expense of operating stations. Under the installed capacity Japan occupied the third place after USA (104 reactors) and France (58) in the global nuclear power engineering industry. To 2017 it was planned to bring the level of nuclear power engineering industry in the country up to 40%, in 2030 – up to 50% and ensure the closed nuclear cycle. Under the density of NPP location (in kW per 1 km²) Japan occupied the fifth place after Belgium – 194.1, South Korea – 188.5, Taiwan – 138.3 and France – 116.0.

14 nuclear power units are located in the northern prefectures Miyagi, Fukushima, Ibaraki. As a result of March earthquake of 2011, 11 units were stopped automatically. All the reactors at the north-east of Japan belonged to the type of boiling body water-water reactors BWR, second under prevalence design of nuclear reactors in the world

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with design operation period of 40 years [24].

The nuclear power plant Fukushima-1 was included into 25 largest NPPs of the world (6 power units with capacity of 4.7 GW). This is the first NPP (first power unit is commissioned in 1970) built and operated by Japanese company TEPCO under the design documentation developed in the 60-ies – early 70-ies of the last century. Except the time for scheduled repairs and reloads of fuel the operation period of the first power unit achieved 40 years, and in 2014-2015 it should be decommissioned. NPP Fukushima-2 with total capacity of 4 GW also operated by this company is located 11.5 km to the south.

The reactor plants for I, II and VI power units were built by American corporation General Electric, for III and V – by Toshiba, for IV – by Hitachi. All 6 reactors are designed by General Electric. The architectural design of power units was performed by Ebasco.

The engineering structures were installed by Japanese company Kajima. The reactor plant is equipped by the system for maintaining the coolant quality, gas removal (first of all, hydrogen formed during the radiolytic decomposition of water in the active zone), removal of residual heat from the active zone at the stopping of reactor and safety systems. In 1990-2000 the operating organization took a number of additional measures on the management of off-project serious accidents and introduced the changes into the NPP layouts and procedures [20, 24]. During the time elapsed since the commissioning of these units they were subjected to reconstructions aimed at the exclusion of the mistakes of staff.

The land plot planning level for the location of main buildings is located 10 m higher than the sea level. The protective dam 5.7 m high is built to protect the berth and water intake facilities against the impact of waves.

I unit of Fukushima-1 reached the age of 40 years on March 26, 2011. One month before the accident the permit in relation to the extension of license for its operation was obtained.

Very strict requirements are presented to the construction of nuclear power stations in the areas of increased seismic activity, the reactors are disconnected at the smallest threat of nearby shocks of earthquake [3]. Regardless of permanent seismic activity, to the certain time it was possible to avoid the serious incidents at the nuclear reactors. The earthquakes occur in Japan almost daily, the most of them are insignificant and do not cause any damage. However, under the assessment of the

specialists of Japan Earthquake Research Committee, the probability of occurrence during 30 years at the coast of prefecture Miyagi of earthquake with magnitude of 7.5 points is 99%. The destructive earthquake can occur at any point of country located at the joint of four tectonic plates – Pacific, North-American, Eurasian and Philippine. The plates crawl under the North-American and Eurasian plates with speed of 8.5 and 6.5 cm per year respectively. Japan Trench with length of 1000 km and depth of up to 8412 m is located along the eastern slope of Honshu Island. The areas with high sliding during the analyzed earthquake were located not far from the southern fault with maximum sliding of more than 20 cm.

Very often the underwater shocks are followed by tsunami. Herewith, the giant waves are spreaded from the epicenter and their speed can reach 1000 km/h. Nearby the coast the speed of wave decreases to 500 km/h, its height increases and the power becomes more destructive. This time the height of tsunami waves was 23 m. According to specialists, the current earthquake at the north-east of Japan under the capacity exceeds the largest earthquakes in 1923 and 1995. The area of the source of this earthquake was more than 400 km long and about 200 km wide. The Earth crust fracturing continued for 170 sec. The sequence of fracturing and magnitude of earthquake of 9.1 points exceeded the expected. The intensities in the area of NPP Onagawa, Fukushima 1 and 2 and Tokay were more than 5 points. The average soil settlement along the coast of Miyagi district in prefecture Fukushima during this earthquake was about 0.8 m.

The accident at NPP Fukushima-1 demonstrated how high the probability of implementation of the most apocalyptic scenario in the nuclear power engineering industry is. The nuclear power station was exposed practically simultaneously to the impact of two natural factors: earthquake record by capacity (with magnitude of 9.1 points under Richter scale) and tsunami wave record by height. The epicenter of earthquake was located in the ocean at the distance of 70 km from Honshu Island at the depth of 24 km, 80 km to the east from the territory where NPP Onagawa is located and 150 km north-east from both NPPs Fukushima 1 and 2. The tsunami wave nearby NPP exceeded the height of 7 m [17, 18, 24].

The chronology of initial events at NPP Fukushima-1 is as follows [15, 18, 20, 24].

On March 11 at 2:46 PM 9-point earthquake occurred at the depth of 24 km near the coast of Honshu Island. At the moment of earthquake the antiseismic protection of reactors was activated

which disconnected I, II and III power units of Fukushima-1 and respectively the turbine generators. IV, V and VI power units were not operated due to the scheduled maintenance. The fuel from IV reactor was removed in November 2010. Unit No. 5 since January 3, 2011 and unit No. 6 since August 14, 2010 were at the scheduled repair. On the day of earthquake unit No. 5 was loaded with fuel and passed the hydraulic consistency tests; unit No. 6 was loaded with fuel, sealed and frosted.

The shock of earthquakes provoked the disconnection of nuclear power station from the Japanese electric power network but all 13 emergency reserve diesel generators which continued the cooling were activated automatically. The operator of station – Tokyo Electric Power Company (TEPCO) – informed the corresponding officials on the event at NPP. After the recording of earthquake the system of notification on the possibility of tsunami was activated. There were three notifications about tsunami: in 3, 28 and 44 minutes after earthquake. The organization of announcement was complicated by multiple destructions of communication systems after earthquake and the absence of their electric power supply.

At **3:27 PM** the first tsunami wave struck the nuclear power station. The observed level of tsunami at Miak point was 8.5 m and more, at Ayukawa point in Ishinomaki – 8.6 m and more and at point soma – 9.3 m and more. Secondary main tsunami arrived at **3:35 PM**. The level of water on the scale of sensor was 7.5 m. The total area of flooding was 561 km².

The emergency condenser of the first power unit designed for cooling of steam inside the pressure vessel is damaged. At **3:46 PM** 14-meter tsunami wave exceeded the protective dam having flooded the facilities of NPP Fukushima-1, disabled the reserve diesel generators of 1, 2 and 3 power units (except one located in its building at the relatively high place on the first ground floor of reactor building No. 6) and washed out the fuel tanks. The reactor plants of units No. 1-5 were disconnected from emergency electric power supply, unit No. 6 at one operating diesel generator did not lose completely the alternating current. The generators were designed for emergency frosting of reactors. Also all the system for supply of sea water for the systems of removal of heat from the NPP equipment were flooded.

During the first hours after complete deenergization at 3:37 PM on the 11th of March the personnel of station took the measures on the recovery of operation of important instruments, lighting of

block control points (BCP) and organizing the supply water to the reactors and fuel storage basins using the fire-extinguishing systems equipped not only with electric pumps, but also the pumps driven by the internal combustion engines. Practically the work was performed in complete darkness. The electric torches were used. To recover the operation of instruments they used the accumulators of heavy haulers, to recover the electric power supply – the movable diesel electric power stations. Also the measures on the recovery of power supply from the external sources were taken. Continuous repeated earthquakes and warnings on the repeated tsunami disorganized the work.

Due to the absence of electric power supply for instruments and possibility of remote control of equipment the personnel of station faced the serious complications during the emergency operations performance. The telephone communication was damaged. Only the one wired channel between BCP and the accident control center remained. The system started to use the steam pumps with battery supply of valves.

At **6:00 PM** the level of water in the first reactor lowered to the tops of fuel rods. At **7:03 PM** the Prime-Minister Naoto Kan declares the 4th emergency nuclear status under the International Nuclear Event Scale (INES) (accident with local consequences).

At **7:30 PM** the fuel rods of the first reactor completely appear above the surface of water. At **9:23 PM** the Government of Japan issues the order about the evacuation of people in the radius of 3 km around NPP Fukushima-1 and the necessity to stay in premises for inhabitants of 10-km area.

The extended deficit of electricity at Fukushima Daichi exhausts the batteries of reserve direct current modules, and it was impossible to control the parameters and control remotely the pipeline fittings. The water level in reactor already was not under control. The pressure in nuclear reactors increases due to the decrease in the level of coolant. TEPCO declared that the level of pressure in the first reactor exceeds by two times the normal. At **4:36 PM** due to the failure of system for cooling the active zone TEPCO in accordance with applicable rules declared the emergency situation at NPP.

The steam was removed and condensed in toroidal basin, at the lower part of reactor premise. When several meters of water above the active zone evaporated (in the 1st unit this occurred after 8 hours) the fuel elements (FE) were exposed and overheated. At the temperature of 1200°C the

water steam reacted with zirconium shells of FE. The speed of this exothermal reaction depends not only on the temperature but also on the steam pressure. The pressure in the protective jacket (containment) and toroidal condenser (pressure compensator – bubble condenser) increased quickly. At **4:15 AM on March 12** the pressure in containment according to the records of personnel reached 840 kPa (design pressure is 427 kPa). At 5:14 AM the increase of radiation at the site continues that complicates the performance of work.

TEPCO management faced the choice: to release the pressure to decrease the threat of explosion or to wait until the active zone will be melted. The tore was the weak place; it exploded. The hydrogen entered the reactor unit premise after the purging of bubbling chamber to ventilation pipe (the premises of reactor building according to the project were used as the secondary protective cover). First spark resulted in the explosion of detonating mixture. This could be avoided if the management of station took the timely decision on the supply of sea water to reactors. But due to the sea water the operation of reactors was impossible in future. Due to the commercial interests the decision to use the sea water was postponed at that moment.

At **5:30 AM**, regardless of the high risk of hydrogen combustion due to the reaction of oxygen, it was decided to release the steam containing small amount of radioactive substances to the protective cover in order to decrease the pressure inside the 1st reactor of Fukushima-1. Due to the pumping of fresh (sweet) water in the first reactor at 5:46 AM on March 12 the development of the reactor body damage was suspended. At 6:50 AM the core of the first reactor melted and fallen on the reactor body bottom (at that moment it was not known). To prevent the containment destruction at 9:15 AM they opened manually by 25% the motor valve for the discharge of vapor and gas mixture from the protective cover to ventilation pump.

At 10:09 AM the small amount of steam was discharged to atmosphere in order to decrease the pressure in the reactor of I unit of Fukushima-1. The decrease of pressure also was necessary to allow for the fire-fighters due to the exhausted clean water reserves to pump the sea water directly to reactor. At 2:00 PM the manual release of pressure in the protective cover was performed. At 2:50 PM the pumping of water to the first reactor is stopped.

The explosion in the upper part of reactor building occurred at 3:36 PM. The calculations demonstrate that about 800 kg of hydrogen could

be emitted in the reactor of unit No. 1. Due to the explosion the roof and external walls of operating hall in the upper part of reactor building as well as the roof of the waste utilization building were destroyed. During explosion the radioactive substances were emitted to environment. Due to the melting of fuel and further leakages of gas from the protective cover all the noble gases, about 1% of tellurium, about 0.7% of iodine and about 0.3% of cesium were emitted to environment.

At **7:04 PM** the pumping of sea water to the reactor of the first unit was started, directly to the protective cover of reactor with the help of fire fighting vehicles.

The pressure in the second reactor of Fukushima-1 was regulated by the automatic safety valves the operation of which together with cooling system of the isolated active zone RCIC resulted in the increase of temperature in the bubbling chamber. At 3:30 PM the trend to the increase of temperature in the bubbling chamber was recorded. At 3:36 PM the pumps of system for removal of residual heat RHR were subsequently stopped due to the damage by tsunami of the electric power supply systems. Due to the flood they lose two diesel generators, power distribution panels and emergency buses, including the direct current system, sea water pumps for cooling. Complete de-energizing of unit occurred. The devices for remote control, lighting, removal of residual heat from reactor were disconnected.

At 10:00 PM the level of water in reactor was sufficient (+3 m). From 4:20 to 5:00 AM on March 12 the level of water in the condensate reserve tank decreased, and increased in the bubbling chamber. To continue the RCIC system operation the intake of water for it was transferred to bubbling chamber, i.e. the cold water from the condensate reserve tank was replaced by the bubbling chamber water heated by the discharges of steam from reactor through the safety valves. At 12:00 AM on March 12 the pressure in the bubbling chamber exceeded the pressure in protective cover. The reverse flow of non-condensing gases from the bubbling chamber to protective cover occurred; on March 13 the pressure is still high. To decrease it, it was decided to discharge the radioactive steam to atmosphere.

On March 12 TEPCO acknowledged the failures of the frosting systems for three of four NPP units. The temperature in the active zone of reactor exceeded 1800°C due to the absence of cooling. As a result of thermal dissociation the water remained in the active zone decomposed to oxygen and hydrogen. At the achievement of the

limit pressure of gases and explosive concentration of the oxygen and hydrogen mixture the explosion occurred which caused the destruction of structures, including the cover and protective body of reactor. This resulted in the emission to atmosphere of radioactive nuclides and significant thermal, gas and chemical contamination of environment. The press contains the information on the detection of radioactive cesium near the station. The intense thermal contamination resulted in the occurrence of high temperature fires. Further emission of thermal energy in the active zone of reactors in the absence of heat removal resulted in the FE melting and formation of corium which started to evaporate under the impact of high temperatures.

The fuel rods of the first unit were visible above the water 4 hours after the emergency disconnection of station, and they completely melted in 16 hours. The melting of FE of units took 60 hours, melting of reactor – 100 hours.

At **2:40 AM** the power backup batteries for the pressure compensator of III reactor failed. At **4:15 AM** the fuel rods of III reactor were exposed. The sea water pumps performing the removal of heat from the stopped reactors No. 5 and 6 were lost due to the tsunami. After the loss of the cooling systems the pressure in reactors at the expense of residual heat increased having achieved almost 8 MPa in unit No. 5. At 6:06 AM on March 12 the pressure was released from the body of reactor No. 5, but it continued to grow due to the residual heat emission.

On **March 12 at 5:44 AM** the evacuation from 10-km zone was announced. At 3:30 PM they announced the evacuation of inhabitants from 3-km zone in the radius of Fukushima-1, and at **6:25 PM** – the inhabitants from 20-km zone around NPP Fukushima-1. At **3:36 PM** the powerful explosion of hydrogen occurs in the external cover of the first unit that results in its destruction. 4 workers were injured.

At **9:40 PM** the evacuation zone around Fukushima-2 extends to radius of 10 km.

At unit No. 3 after the stop on March 13 at 2:42 AM of HPCI system the supply of water to reactor was started only at 9:25 AM, and the melting of fuel – at 7:40 AM. Same as at unit No. 2, the delay in the supply of water to reactor is associated with problems of discharge pneumatic fittings occurred during the decrease of pressure in the reactor. The problems of the pneumatic fittings control occurred at the other moments of accident, including during the release of pressure from the protec-

tive cover that was required by the technology “discharge–makeup”.

On March 13 at 4:00 AM the pressure in the reactor body lowered to 0.5 MPa, and at 2:00 PM the increase of pressure to 0.6 MPa was recorded, at 6:00 PM the pressure under cover again began to decrease. It is supposed that these events are associated with the decompression of the reactor body and protective cover.

On **March 13** it was announced on the possible partial melting of III reactor. To **1:00 PM** the pressure in I and III reactors is decreased and they are again filled with water and boric acid to cool and restrict the nuclear reactions.

The mass evacuation of population from 20-km zone around Fukushima-1 (about 170 thous. of persons is evacuated) and 10-km zone around Fukushima-2 (about 30 thous. of persons) was started.

On March 3 using the condensate makeup pump which obtained the electric power supply from emergency diesel generator of unit No. 6 the water was successfully pumped to the reactors of units No. 5 and 6. After the 14th of March the pressure in reactors was regulated using the control of safety valves of reactors, and the level of water – through the repeated filling of reactors with water from the condensate reserve tank using the condensate makeup pump.

In the morning on March 14 the pressure buildup in the body of reactor No. 2 accelerated, since 11:30 AM the level of water in the reactor began to decrease. The pressure buildup continued till 1:25 PM, about 12:00 RCIC system stopped, at 4:20 PM the level of water in reactor decreased to the level of fuel assemblies that meant the reactor cooling loss. The operating organization informed about it. At 4:34 PM they started the opening of safety valves in order to decrease the pressure in the reactor body by the alternative pumping of water using the low-pressure fire pumps, to 6:00 they recorded the decrease of pressure, the level of water in reactor decreased.

Due to the existing problems of the supply of air to control the pneumatic drives of safety valves till the first hours of the 15th of March the insidious change of pressure occurred in the reactor body and protective cover and respectively of the water level in reactor. At 7:54 PM the pumping of sea water to reactor using the fire pumps was started. Therefore, the break in the cooling of active zone from 1:25 PM was 6 hours 29 minutes, the fuel melted and transferred to the lower part of reactor body. The alternative pumping of water was insuf-

ficient, and 80 hours after the earthquake at 10:50 PM on March 14 the reactor body was damaged. It was supposed that the water left the lower part of reactor body through its incompactness.

At 00:00 AM on March 15 the repeated release of pressure in the protective cover was performed. At 6:10 AM the explosion of hydrogen occurred. The reactor building is not damaged; the roof of adjacent waste utilization building is partially destroyed. The radionuclides were emitted to environment, and the doses of radiation in premises increased. It is supposed, that to this moment the steam-zirconium reaction occurred in the reactor and the generated hydrogen (according to the calculations – from 350 to 800 kg) through the open safety valves of reactor entered the bubbling chamber where it exploded. The calculations demonstrate that the noble gases, 0.4-7.0% of iodine, 0.4-3.0% of tellurium and 0.3-6.0% of cesium were emitted to environment.

On March 14 at 9:00 AM new powerful earthquake with capacity of 6.2 points occurs at the coast of Honshu.

On March 14 at 11:01 AM the explosion of hydrogen (under calculation – about 600 kg) occurred in the upper part of III power unit building, 11 persons were injured. The reactor and its protective cover are not damaged. The explosion destroyed the service hall of reactor, north and south external walls of the floor located under this hall and the waste utilization building, fired the oil for the system of control the rotation of recirculation pumps located in the seriously damaged western part on the 4th floor of this building, and the water supply of the second unit is violated. II reactor contained the water below the normal level (it was considered that it is stable regardless of that the pressure inside the reactor was high). According to TEPCO, no emissions of radioactive substances occurred, except for ones emitted during the discharge of steam.

The explosion damaged the temporary colling systems, created the problems with ventilation systems that resulted in the most serious condition of II reactor. **On March 15** the explosion in the pressure compensator caused the damage of cover of II unit. The fire affected the used fuel rods occurred in IV power unit. The level of radiation at the station increased significantly. The calculations demonstrate that the noble gases, 0.4-0.8% of iodine and 0.3-0.6% of other nuclides were emitted to environment. The equivalent radiation dose in premise in the close vicinity to III power unit was 400

mZv/h (0.1 mZv/h is considered as the natural radiation level) [1].

The zone in the radius of 30 km around the station is declared as closed for aircrafts. According to certain data, 185-200 thous. of persons were evacuated as of March 15. The departure of foreigners begins – many foreign companies and representative offices evacuate their employees from Japan. USA starts the preparation to possible coming of radioactive cloud. World faces the new wave of protests against the nuclear power stations [2, 4, 22].

In the building of unit No. 4 on March 11 due to tsunami one operating emergency diesel generator and the sea water pumps were stopped; the distribution devices were flooded. The cooling and water supply functions of the used fuel basin were lost. Till 4:08 AM on March 14 the cooling of water in the used fuel basin of unit No. 4 was absent and the temperature of water raised to 84°C. The stored used fuel was heated to high temperature due to the low level of water, and the explosion was caused by hydrogen as a result of the water vapor reaction with zirconium in the FE shells. In addition, due to the damage of active zone the large quantity of hydrogen was formed at the adjacent unit No. 3, and its part was discharged from containment to the ventilation pipe common for units No. 3 and 4 (the exhaust air duct of unit No. 3 is connected to the same air duct of unit No. 4 to their entering to the ventilation pipe shaft).

The hydrogen during the ventilation of containment of unit No. 3 could flow to the premises of unit No. 4. At 6:10 AM on March 15 the hydrogen exploded in the reactor building No. 2. The whole upper part of the reactor service hall, western wall and the wall of floor below this hall along the staircase were destroyed. As a result of external inspection after explosion no leakages of water and cracks were detected; the fuel in the used fuel basin of unit No. 4 is not damaged.

Due to the hazarously increased level of radiation (up to 1 Zv/h) TEPCO suspended the work at station and evacuated the personnel. In the morning of March 15 their number was 800 persons, till evening it reduced to 50 persons only. Due to high radiation the employees could stay at the control point for not more than 10 minutes.

On March 16 at 2:30 PM TEPCO declared that the water at the facility for storage of fuel rods of IV power unit can boil increasing the probability of achievement of critical vulnerability of fuel rods. At 9:38 AM the fire was detected in the north-western part of the fourth floor of reactor

building but at 11:00 it stopped. At 5:45 PM the white smoke probably coming from III power unit appeared above Fukushima-1. The press contains the information about the detection of radioactive cesium near the station. Emperor Akihito addressed the population by TV that occurs only in the exclusive cases. The filling of V and VI power units with water was started.

On March 17 the civil defense helicopters four times discharged the water on reactors of III and IV power units. In the second half of the day it was declared that IV reactor is filled with water and none of the fuel rods remains open.

The work on recovery of external electric power supply for all six power units of Fukushima-1 was started. The flooding of lower marks of turbine building where the main amount of cable routes were located with radioactive water which could not be pumped complicated the installation of new cables and their connection to board devices. Many board devices required drying and testing before the supply of voltage. The territory was jammed by the residues of buildings and transport destroyed by the earthquake and tsunami. It was necessary to remove the damages in the external electric power supply equipment or created the temporary bypass circuits.

The explosions resulted in the damage of temporary utility lines and fire fighting vehicles. To extinguish the fires and cool the damaged reactors the liquidators used the survived stationary means, portable devices, floating means and flying machines able to supply the sea water to the center of accident, the fire fighting vehicles equipped with motor driven pumps. To supply the water through the floorings destroyed by explosions they used the water jet cannons for riot squad and construction concrete pumps which were the most appropriate for such operations. But their productivity was insufficient to eliminate the intense heat emission in the damaged reactors.

From **7:00 PM** the policemen and fire-fighters using the fire hoses with high water pressure tried to spray the water above III power unit. The water was supplied to the upper part of destroyed protective body of reactor, entered the high temperature zone but not on the heat emission source and immediately was converted into water decomposed into oxygen and hydrogen resulted in new explosions. To spray the water directly into reactors the president of Chio Construction proposed to use two concrete pumps installed on the trucks.

The destruction of buildings of I, III and IV units played also a positive role: the cooling of the containments of reactors was improved, therefore,

the reactors themselves. Survey with thermal imagery device demonstrated that the temperature of roof coating of II unit the building of which was slightly damaged exceeded 150°C. It is possible to suppose which was the temperature in the building itself and moreover – inside the reactor. The same picture is specific for units I and III.

On March 18 Tokyo fire-fighting department sent 30 fire fighting vehicles with 139 fire-fighters and team of rescuers, including the fire-fighting truck with 22 m hydrostatic pressure pump for spraying of the cooling water. **On March 19** they were replaced by team consisting of 100 Tokyo and 53 Osaka fire-fighters. The water was sprayed for 7 hours that allowed for decreasing the temperature at III unit to 100°C, and the level of radiation – from 351.4 to 265 mZv/h. The high level of radiation (150 mZv/h) was detected at the territory of 30 km north-west from Fukushima-1. Japanese authorities assigned level “5” to the situation. The loss of cooling in the active zone of IV power unit was classified as level “3”. TEPCO informed that all four power units of Fukushima-1 were transferred to the “cold stop” mode, i.e. the temperature of coolant in them was below 100°C, and all the cooling systems are completely able to work; their stable operation is adjusted.

On March 19 they installed the temporary sea water pump to activate the cooling systems of RHR reactors of units No. 5 and 6. The fuel in the reactors and storage basins is cooled alternatively through RHR system switching. On March 20 at 2:30 PM reactor No. 5 and at 7:27 PM reactor No. 6 are brought to the “cold stop” condition.

On March 20 II power unit was connected to external electric power supply and the equipment recovery work continued. The repaired diesel generators of VI power unit allowed for starting the cooling of V and VI power units that lowered the temperature of water in their basins to normal. General Secretary of the Cabinet of Ministers Edano declared that the nuclear complex Fukushima-1 will be closed after the elimination of crisis. From March 21 the limitations on the use of different agricultural crops were introduced.

At 3:55 PM on March 21 a grey smoke appeared above III power unit. The work on the electric power supply recovery was suspended due to the probable occurrence of fire. **At 6:22 PM** white smoke accompanied by temporary increase of the level of radiation was noticed above II power unit. **21 On March 21** TEPCO declared that with the electric power supply recovery the crisis will not be eliminated because the damaged cooling sys-

tems cannot be repaired and shall be replaced. **On March 22** the smoke above II and III power units is preserved. The repair operations continued because there was no increase in the level of radiation. The pumping of sea water to I, II and III power units continued. The reserve electric power supply cables were connected to all 6 power units.

The employees were evacuated again due to the black-grey smoke appeared again above III reactor **on March 23**. Small fire occurred inside the damaged reactor building. The quantity of water inside the reactor is increased at the expense of the recovered water supply system of I power unit. The level of radiation exceeding the normal by two times is detected in Tokyo drinking water.

On March 21 the voltage from external source is supplied to unit No. 5, on March 22 – to unit No. 6, the BCP lighting of unit No. 3 is recovered; on March 23 the cables for supply of mechanisms at unit No. 2 were connected; on March 24 the lighting at BCP of unit No. 1 is recovered.

As of March 23 more than 320 thous. of people were evacuated, taking into account the people evacuated because of tsunami. Till March 24 the level of radiation near the station decreased to 200 mZv/h. Three workers were exposed to radioactive irradiation because of radioactive water entered the protective outerwear, two employees required urgent hospitalizing. The IR-examination of the buildings of reactor demonstrated that the temperature of I, II, III and IV power units decreased to 11–17°C, temperature in reactor circuit is 30°C.

On March 25 the radioactive water is also detected in turbines of I and II power units. Probably, the protective cover of reactor had the opening. The content of iodine-131 in sea water was 50 Bq/ml that exceeded the standard by 1250 times **On March 26** the level of radiation near the station is still high. It was possible to fill the reactor with fresh water delivered by two US Navy barges instead of the sea water to the required level. **On March 27** the level of radioactive contamination of water at II and III power units was higher than 1000 and 750 mZv/h, respectively. Technical works on the restoration of damaged cooling system of power units are postponed. Video of civil defense helicopters allowed for obtaining a more accurate picture of damage:

- white smoke and steam above the buildings of II, III and IV power units;
- roof of the building of II power unit is strongly damaged, but still intact;
- building of III power unit has no roof which is destroyed by the explosion of hydrogen occurred about two weeks after the accident;

– the walls of building of IV power unit are also destroyed.

On March 28 the radioactive substance from the melted fuel rods of II power fell into the water used for cooling which leaked into the basement of the building where the turbine units of II power unit are located. The amount of water pumped into II power unit was reduced from 16 to 7 t which would cause an increase in the reactor temperature. Because of the highly radioactive water the work on restoring the cooling pumps and other facilities of I-IV power units. A small amount of plutonium was found in five samples taken **from March 21 to March 22** in two places at the station (in the field of solid waste, and in the field).

On March 29 the spraying of water above I-III reactors continued. Radioactive water began to flow into the technical channels outside the buildings of three power units. It was not possible to continue the recovery of cooling and other automated systems.

On March 30 chairman of the board of directors TEPCO Katsumata announced at the press conference that it is not clear how the problem at the station could be solved. The urgency was to remove the radioactive water from the basements of buildings and salt from the reactor formed due to the use of sea water.

On March 31 the radioactive water is pumped from the technical channel near I reactor to special vessel near IV reactor. The water from condensers of II and III power units is pumped into external reservoirs. The world's largest concrete pump is sent to Fukushima from USA. 62-meter pump was donated by Chinese manufacturer SANY.

On April 2 it was found that through 20-cm crack in the concrete channel for the power supply cable of pumps connecting the sea and II power unit, the contaminated water from II power unit is discharged into the sea.

On April 3, despite the introduction of a water-absorbing mixture of polymers, sawdust and shredded paper the leak of radioactive water into the sea continues. The level of radioactive contamination of water was 1 Zv / h.

On April 3 the transfer of pumps pumping the water into the reactors of units No. 1, 2 and 3 to electric power supply from an external electric power source was performed.

On April 4 TEPCO started to discharge the low radioactive water into the Pacific Ocean. This allowed for using the station RW storage for storing of more dangerous radioactive water. It was

planned to discharge 11,500 tons of radioactive water into the sea.

On April 6 IAEA insisted on the introduction to the opening of sodium silicate (liquid glass) to prevent the leakage of radioactive water. The Minister of Economy, Trade and Industry decided to introduce the nitrogen into the protective cover in order to prevent the hydrogen explosion in the cover of unit No. 1.

During the whole March and April there are new shocks of earthquake near the island of Honshu.

On April 7 at 1:31 AM they initiated the introduction of nitrogen into the protective cover of I reactor in order to dilute the accumulated hydrogen and exclude the atmospheric oxygen, the pressure in the cover was increased by 0.05 MPa. It was assumed that the pipes for introduction of steam and gas mixture to the bubbling chamber are not immersed in water. Therefore, the efforts to determine the level of water in the bubbling chamber were made.

The shocks with capacity of up to 7.4 points repeated. Most of new workers were evacuated from the station. New damage after the earthquake was not recorded, but the temperature of I reactor increased and was accompanied by the release of radionuclides (100 Zv / h) into the well. The instruments displayed a rise of pressure in the reactor.

On April 9 Japan is still struggling for storage of water in the reactors for their cooling in order to prevent the further melting of nuclear fuel elements. TEPCO purchased two 95-ton automobile concrete pumps delivered by Russian aircrafts AN-124. They can be controlled remotely from a distance of two miles, and the water can be sent directly to the damaged reactors.

On April 11 the coolant supply to I and III power units is interrupted due to the loss of power as a result of earthquake.

On April 12 Japan formally raised the level of accident to 7 under the International Nuclear Event Scale (similar to Chernobyl accident). Due to the hydrogen explosion at I power unit on **March 12** and emissions from III power unit the amount of the radioactive iodine emissions reached 190,000,000,000,000,000 Bq.

During the Chernobyl accident 10 times more radioactive nuclides were released into the atmosphere than at the accident Fukushima-1 until April 12. Total amount of radioactive material stored at Fukushima-1 is 8 times more than in Chernobyl. Emissions at Fukushima-1 continued. Following the suspension of operations on the cooling of exposure

basin of IV unit (due to a false warning on the fullness of basin) the basin water temperature increased to 90 ° C. Radiation level on the surface of basin reached 84 mZv / h.

On April 15 it was reported that the radiation level of water in some areas of the plant was 1000 mZv / h, indicating a continuing leak of radionuclides from the active zone.

Sixth week: in I, II, III reactors the fuel rods melted, the fuel has gone into the lower sections of reactor. It was assumed that the fuel is uniformly dispersed on the lower parts of reactors which made "unlikely" the further renewal of the fission process.

On April 17 they adopted a program of urgent emergency measures: cooling of reactors and basins of the used fuel through the organization of a continuous closed-loop cooling water circulation through them; reliable removal of heat from the used fuel located in the basins; location, collection, storage, processing and re-use of contaminated water; protection against the penetration of unauthorized penetration of contaminated groundwater into the sea; reducing the impact of the release of radionuclides into the atmosphere and the earth's surface and wind transport by temporary sheltering the destroyed buildings by polymeric coating and spraying the soil and dust fixing compositions; monitoring radiation doses liquidators and the population and evacuation planning; forecasting of possible consequences and are protective measures against tsunamis; increasing the earthquake resistance of buildings and structures damaged.

On April 18 two robots entered I and III power units of Fukushima-1 and measured the temperature, pressure and radiation level (49 mZv / h in I power unit and 57 mZv / h inside III power unit). The robots also entered the building of II power unit, but the high humidity (over 90%) in the building prevented the survey (the camera lens is fogged up).

The test spraying of chemicals to precipitate the radioactive dust in the area of 1200 m² is performed.

On April 19 they began to pump the radioactive water from the basement of II power unit and tunnels into the waste recycling device. According to the measurement of April 20, in seawater 15 km from the station the radiation level exceeds the norm by 5 times. On April 21 at 11:00 AM they provided the orders to clarify the boundaries of the evacuation zones in accordance with requirements of the legislation on natural disasters.

On April 22 President of TEPCO M. Shimutsu officially apologized to the governor of Fukushima prefecture Yu. Sato for the nuclear crisis followed the earthquake and tsunami of March 11, 2011. At 2:30 PM the orders on the determination in the event of danger zones with shelter indoors and possible evacuation zones and evacuation zones were given.

On April 26 they conducted the spraying of chemicals to precipitate the radioactive dust.

On April 27 the radiation levels measured by robots inside I power unit reached its highest level - 1120 mZv / h.

On April 28 the Advisor to the Prime Minister recognizes that the Government of Japan to prevent the panic deliberately understated the true values of radionuclide releases. The level of danger from the very beginning complied with "7" under a scale of events.

The first results of new TEPCO strategy to create a large "water sarcophagus" at the first three reactors were positive, and by the end of May, the situation at Fukushima-1 was relatively stable.

In May, to prevent the spread of radioactive dust over the buildings emergency NPP they sprayed the adhesive substance. The radiation levels at the boundaries of the station reached normal (less than 1 mZv / year). Despite the achievement of "cold shutdown" NPP Fukushima-1 continues to discharge the radioactive water resulting in that the Pacific Ocean has got a large amount of radioactive substances. Because of the hole in one of the channels of cleaning system 120 tons of highly radioactive water spilled out of it. The level of radiation at the spill site by hundreds of times exceeded the norm - 140 thousand Bq / cm³. The level of radioactive cesium in fish caught nearby Miyagi Prefecture exceeded 360 Bq / kg at a rate of 100 Bq / kg which forced the local fishermen to stop the fishing for redfish [24].

Using computer modeling, the Japanese Agency for Research on Earth and Ocean JAMSTEC create a map for spread in the ocean of cesium-137 in the period from March 2011 to 27.01.2012. Scientists have calculated the movement of radioactive particles resulting from the ocean currents, taking into account the half-life of the radionuclides. The analysis demonstrated that after 2 months the contamination of the nearest water area will be lower than the chances of detection by standard instruments.

On May 5 the workers entered the building of I reactor to connect the air filtration system for the absorption of radionuclides inside the building, which will start the replacement of cooling sys-

tems; on May 8-9, they opened the double doors on the north side to ventilate the building.

On May 11, the level of cesium-134, -136, -137 and iodine-131 increased.

On May 12 TEPCO engineers confirmed that the melting of nuclear reactor fuel elements has occurred, and the fuel elements have fallen to the bottom of the reactor. The fuel rods of I reactor are completely covered with water. The existence of holes in the bottom of the reactor protective cover which were burnt by the molten active part is confirmed. Nuclear fuel leaked into the protective cover shell, damaged by explosion during the accident. The active part was damaged in I, II, and III reactors.

On May 15 the radiation level on the ground floor of I power unit was 2000 mZv / h. Workers are allowed to stay there for no more than 8 minutes. A large amount of water is discharged from the reactor protective shell to the basement. 11 m high basement is half filled with water.

According to TEPCO, the fuel rods of I reactor could be seen above the water 4 hours after the earthquake, and emergency shutdown station and were completely melted in 16 hours.

On May 18 four workers entered the building of II reactor to measure the level of radiation. They got a dose of 3 and 4 mZv / h.

From May 10 to May 22, 2011 at least 250 tonnes radioactive water leaked to the Pacific Ocean from III reactor.

On May 24 TEPCO acknowledged the melting of active zones of II and III units. The melting of fuel rods took 60 hours, the reactor meltdown - 100 hours (after 9 point earthquake).

On June 2 the studies conducted by Tokyo Denreku in two places about 3 km from the coast found on the seabed strontium-89 and -90 with radiation levels up to 44 Bq / kg. Studies have been conducted 20 km to the north and south of the nuclear complex. On June 12 the concentration of radioactive strontium in seawater by 240 times exceeded the permissible parameters. Radioactive strontium is also found in groundwater near the 1st and 2nd units at the NPP territory.

On June 19 TEPCO begun to dismantle the upper destroyed floor of building of IV power unit. On June 28 it was reported that the 3rd and 4th power units of emergency NPP will be covered by 62 special sheets with thickness of 1 mm, which will be attached to the metal structures of buildings. **On June 30** the low radioactive water from NPP Fukushima-1 was injected to artificial floating island Megafloat with length of 136 m, width - 46 m,

height - 3 m, which can accommodate 10 thousand tons of water.

On July 16 the first phase of liquidation of the accident at the plant which meant the beginning of stable reactor cooling and pumping of nitrogen to prevent the hydrogen explosion is completed.

Attack on March 11, 2011 has quite a mighty power. The earthquake and tsunami spawned the technogenic disaster at the nuclear power station, which, in turn, has led to environmental and humanitarian catastrophe on a large area. There were the fires in 6 prefectures, including the largest refineries Sendai and Ichihara. A number of highways, railways were completely destroyed; ports were closed, 4 big cities were flooded. Sendai airport was washed with water; 5 airports, including Tokyo and Sapporo, stopped working. More than a million homes lost the power and water supply. The environment was infected; people were forced to leave their homes hurriedly, perhaps forever. The number of deaths in 12 prefectures of Japan amounted to 15467 persons, 7482 were reported as missing, and 5388 people were injured. Economic damage from the tsunami exceeded 300 billion dollars. All this together caused the heavy psychological trauma not only to the people of Japan, but also the entire population of the globe. Huge economic losses from the accident fell on the shoulders of the international community [13, 21, 23, 25].

Exposure to the elements was felt by the Russian territory, in particular the Southern Kurils and Sakhalin. Near the island of Shikotan waves rose to a height of three meters, near Iturup - to two. Ships standing in the ports were sent out to sea, the residents were ordered to leave the area of coast. After MOE warning 11 thousand people left the danger zone [1, 19]. As soon as the giant waves reached the shores of the Antarctic, the threat of a tsunami was announced across the whole Pacific area- Philippines, Indonesia and Latin America. [14]

The current situation at NPP Fukushima-1 is completely stabilized. Above I, III and IV units the protective concrete sarcophagus shall appear. Now they are covered with protective caps from polyester panels. Preparations for the removal of used rods from the exposure basins located above the reactors were started.

In the assessment of the effects of radiation accidents according to radiological analysis it is possible to distinguish two periods of intense release of radioisotopes: the first corresponds to the explosions at the reactors from 12 to 15 of March,

when the short-lived radionuclides were emitted to atmosphere, and the second period - from 20 to 24 of March during strong heating and depressurization of the reactors.

If at the first stage the level of radioactivity declined very rapidly, almost to the natural values, at the second stage, when the area around NPP was contaminated with radioisotopes of iodine and cesium, the decline in activity has become less dynamic. **On March 30-31**, there was a significant rise of radioactivity due to the hydrogen explosion at unit I **on March 12** and emissions from III unit. The amount of iodine-131 emissions reached to 190 thousand TBq (1 TBq equivalent to 1 trillion Bq). **On March 15** the level of accident at NPP Fukushima-1 was increased to 7, reaching the evaluation of Chernobyl accident.

Due to the prevailing winds in the emergency period in the area of Japan, the bulk of radionuclides emitted went to the northeast and east toward the Pacific Ocean, reaching the shores of the United States (Fig. 1).

The presence of radioactive isotopes was detected thousands of kilometers from the scene of the accident [1, 14]. The main radionuclides released from the reactors, - iodine-131 and cesium-137. In total, $1,5 \cdot 10^{17}$ ($1,8 \cdot 10^{18}$ - at Chernobyl NPP) Bq of iodine-131 and $1,2 \cdot 10^{16}$ ($8,5 \cdot 10^{16}$ - at Chernobyl NPP) Bq of cesium-137 were emitted into air. The estimates of the amount of radio-active substances, discharged into the sea from the contaminated water, showed that a block No. 2 discharged $4,7 \cdot 10^{15}$ Bq, unit No. 3 - $2,0 \cdot 10^{13}$ Bq, units No. 5, 6 - $1,5 \cdot 10^{11}$ Bq.

At the time of the accident the Japanese government had a stock of 250 thousand doses of potassium iodide; 200 thousand doses have been allocated to the population for prevention during the very first period. The Government of Japan believes that the overexposure of the thyroid gland in the population is unlikely. People were resettled within a radius of 20 km from Fukushima-1. People living within a radius of 20-30 km from the plant were recommended to resettle voluntarily. For some clusters the decision on mandatory evacuation was taken. No significant effects of radiation on human health are expected. No doses higher than the norm of accidental exposure were recorded [1, 9, 13].

The level of radiation caused by the presence of "Japanese" radionuclides detected in a number of countries is far below the background levels [21, 22, 24, 25]. At a distance of 30 km from the plant the radioactive radiation level is 0,2-26 mZv / h (background values - 0.05-0.1). For comparison: in the

plane at an altitude of 9 thous. m - 4-7 mZv / h, in a mountainous area - about 0.5 mZv / h.

It is expected that the reactor cooling system will run for 2-3 years, after that the systems will be

disabled. Currently, there are sealing problems in the damaged containments of reactors No. 1, 2, 3.

Fig. 1. Zone of nuclear clouds as a result of the accident at the nuclear power plant Fukushima-1

Within 10 months TEPCO could only guess what is happening inside the reactor after the fuel melting. In **January 2012**, it was possible to get the first shots by using a fiber-optic camera. The endoscope was introduced through a hole in reactor II at a height of 7 m above the bottom of the containment. The confirmation that the fuel remains relatively cool is received.

The leak of highly active water continues from unit IV of Fukushima-1. The exact location of leaks has not yet been set. Leaking water enters the ground floor of IV reactor building.

The total emission of radionuclides of iodine and cesium at Fukushima-1 is corresponding to 10% of volume that were released during Chernobyl accident (excluding uranium and plutonium that were raised in the fire of Chernobyl reactor core). The total capacity of the destroyed reactor Fukushima-1 is almost 4 times higher than IV power unit of Chernobyl NPP. To this must be added the accumulated over 40 years of operation, Fukushima-1 spent fuel assemblies also played a negative role in the accident.

On Fukushima-1 4 power units are irretrievably lost, the Chernobyl - one. Within six months after the accident I, II and III units of Chernobyl were put into operation.

The accident at the nuclear power plant Fukushima-1 is fundamentally different from Chernobyl, where there was a momentary release of radioactive material [12, 19, 20]. On Fukushima-1 there was not an explosion of a nuclear reactor, there was no massive dispersion of radionuclides in the air. The volume of radioactive emissions at Fukushima-1 was 7 times less than at Chernobyl, and was directed mainly towards the ocean. The loss of radioactive contaminated water from the station continues; it is much more difficult to eliminate it. Food requires monitoring, as due to the accumulation by the food chain in fruits, milk, meat it can contain more radionuclides. Also it is necessary to carry out the strict control of water due to the migration of radionuclides in aquifers.

The content of radionuclides of cesium and iodine in a large number of samples taken and tested during the spring and summer in the Far Eastern region of Russia was at the level of sensitivity of measurement or below. In the samples of vegetables and fish taken at the Primorye, Khabarovsk and Kamchatka territories cesium-134 was not detected. The fish samples taken in May in Primorye (navaga) and algae contained iodine-131 (2.9 and 8.9 Bq / kg respectively), the maximum content of cesium-134 in the samples of fish

taqken in Sakhalin and Magadan was 4.7 Bq / kg, in seafood selected in the Primorsky Krai and Sakhalin region - 5.7 Bq / kg. The samples of vegetables in Magadan and Sakhalin regions contained cesium-134 in small amounts - from 0.9 to 1.8 Bq / kg. A conservative estimate of maximum annual doses to the population at the expense of radionuclides of cesium-137 and -134 provides after-following quantities: the islands of Kunashir and Shikotan - 38 mSv / year for the Primorye Territory - 37 mSv / year for the Sakhalin - 24 mSv / year. The maximum individual annual radiation dose of the population according to spring and summer surveys may reach 81 mSv [1].

During the time of the accident at the nuclear power plant Fukushima-1 3 people were killed and 20 people were injured. According to the doctors, the disease state of 149 patients from 610 people admitted to 27 hospitals of Fukushima Prefecture in the first two months after the accident was associated with radiophobia. The Japanese government has allocated 1.24 billion dollars for the health monitoring of residents of Fukushima Prefecture for 30 years. The plan to establish the Agency for Nuclear Safety, responsible for monitoring levels of radiation, which previously served the Ministry of Science and Technology is approved. On the sixth week after the accident a large-scale check of the impact of the accident on human health and the environment was started.

The accident at the nuclear power plant Fukushima-1 changed the people's attitudes towards nuclear power in the world. Twenty-one of the 24 states, home to 60% of the population, immediately after the accident were in favor of the closure of nuclear power plants. The number of opponents of nuclear energy in China, Japan, South Korea has doubled.

The economic damage caused by someone pany TEPCO - the owner of the plant Fukushima-1 has reached 32 billion dollars, accounting for 80% of its value before the accident. The amount of compensation to victims may reach 130 billion dollars. Damage from stopping the nuclear power plant Fukushima-1 and other nuclear stations is estimated as 90 billion dollars annually.

TEPCO plans to build a seawall on the northwest of the island of Honshu to protect the world's largest (in terms of installed capacity) NPP Kashiwazaki-Kariwa from the powerful tsunami. The government commission on nuclear power phase-out plan prepared by the nuclear power plant Fukushima-1. Removing the used nuclear fuel from the pools will begin in 2014 and will end at 6 years of age [1, 11]. Found at a depth of 7 m at the bottom of the

pool soaking unit III fallen tyazhë-Loe equipment (reloading unit weight of 35 tons, fell into an explosion of hydrogen at the III block) can seriously complicate the operation of extracting the fuel from the pool of the block.

Beginning of the most difficult stage of the accident - removing the melted nuclear fuel from reactors - is planned no earlier than 10 years - in 2021. This process will take about 25 years and then after 5 more years, TEPCO experts will dismantle the reactor building and other buildings at the station. Dismantling of NPP Fukushima-1 will last in total for 40 years. The disaster at the nuclear power plant Fukushima-1 has delivered to Japan the challenges for storage and disposal of large volumes of high-level nuclear waste. Their placement on the seismically active islands does not meet the international radiation safety standards. It is necessary to have the substantial sites with the appropriate geological conditions and the consent of the inhabitants on the placement of foreign nuclear waste [7, 8].

The replacement of retired generating capacity in Japan will be compensated by the additional generation on natural gas. Terminals for receiving the liquefied natural gas and gas ships were not affected by the earthquake. Ten Japanese generation companies have tripled the use of petroleum products. LPG consumption increased by 34%.

Japan completely switched to thermal power stations operating on natural gas, coal, oil. The annual cost of the purchase of these fuels could be increased by about 39 billion dollars TEPCO reported an increase of 28.5% of the fuel component of the operating costs of generating capacity. A significant increase in fuel costs is reported by other power-generating companies.

Of 50 remaining units operates the only one. But there may be a situation in which the working nuclear power plants will remain due to the fact that the last two preventive nuclear reactors of NPP Ooi did not have time to become operational until May 5, when it stopped working last nuclear reactor in the country, Tomari in Hokkaido.

The government made a decision on the need to start the reactor, as there was a threat of power shortages in the industrial region of Kansai, which includes the major industrial centers of Osaka and Kyoto. In unfavorable circumstances the lack of electricity could be up to 18.6%. If at least this summer will not start working nuclear power plants, the situation in some areas can become tense.

As of January 1, 2014, the Research Institute of Japan: in operation is only 1 unit; confirmed by

the construction of two new power units of 7 previously planned; Government and the energy companies are planning to restart all operating nuclear power plants, in addition to the plant Fukushima-1.

The new Japanese government led by Prime Minister Shinzo Abe, formed in 2013, adopted a program of further development of nuclear energy, include provisions to tighten nuclear safety. Despite the fact that about 60% of the population is opposed to nuclear power, the parliamentary elections people voted for the party which has taken the decision on the further development of nuclear energy. It is noteworthy that in the mayoral election won Tokyo Yoichi Matsudoe actively advocate for continued use of nuclear energy.

When preparing to restart nuclear power plants in Japan, the following measures are taken:

- Created a new independent regulatory body-conductive - Nuclear Regulatory Agency (NRA), subordinated directly to the Government;
- Submitted 16 applications for re-evaluation of safety and restarting reactors are closest to the re-launch (2015) 5 units;
- in relation to safety more than 28 blocks held public hearings. Thus, as a result, they can be restarted.

The Conference of the IAEA in June 2013 Japanese spokesman confirmed that Japan does not give up nuclear energy development. Undoubtedly, the development of the Japanese nuclear power will continue with a new level of security.

The probability of severe accidents in nuclear power plants sous-exists, it has repeatedly been proven practice (Three Mile Island, Chernobyl, Fukushima-1, all three major nuclear accident occurred at the reactor of the 2nd generation). On the one hand, the lessons of the accident at Japanese nuclear power plant are encouraging because most of the stations of the island nation after swiping natural disaster stopped normally. This confirmed the stability of the nuclear energy to various natural and man-made action. On Fukushima-1 was not a nuclear reactor explosion. Fukushima-1, designed for 7-point earthquake, stood 9 points. If not for the imposition of other factors (tsunami, problems with redundant power supply in the first hours after the accident), the situation could rapidly normalize.

On the other hand, the alarming miscalculations designers and unwillingness of management and staff to make quick decisions (impact lack of basic knowledge among professionals). Formally, at the start of nuclear accident had sufficient means to prevent fuel melting. All units are earthquake-

resistant. Available funds were allowed at the expense of internal resources systems to provide heat dissipation without external water make-up for at least 8 hours, during which it is possible to prepare the reactor systems to water from the provided emergency power. All reactors delay replenishment of water was 5-6 hours at extremely permitted - no more than 2.0-2.5 hours.

Reactor facilities have multibarrier protection systems, but they were not interconnected in terms of elimination of the real abnormal accident. The explosion in the reactor building of unit No. 1 affecting the course of the emergency works, and the explosions on units No. 2-4 evidenced not only by the lack of effective Emergency hydrogen suppression systems, but also the shortcomings of the ventilation systems of the reactor building and questionable necessity of its use as a secondary containment that obviously eliminates manual operations in the performance of the emergency measures. You should also indicate the lack of reliable technology of the work with irradiated fuel inside the reactor after an accident with damage to regular lifting mechanisms.

The situation at the "Fukushima-1" has demonstrated the unpreparedness of the Japanese operators for emergency situations. Emergency instructions were not available. TEPCO company's management having assessed the scale of the disaster in time, and in order to save the company's image, attempted to resolve the occurred extreme problem by itself, that has only exacerbated the scale of the disaster.

The problem of minimizing the risks to life and health of the population requires increased responsibility for making major engineering solutions under conditions of a high seismic activity. During the construction of nuclear power plants, based on the Russian standards of safety in the nuclear industry, it is necessary to take into account the possibility of a tsunami of up to 20 meters in hazardous areas [5-7]. NPP should have the maximum amount of strength, reliability, and survivability. Only high-quality materials should be used in their construction. It requires new technologies to protect facilities with increased risk. NPP is the object of ultra-high-risk designed for many years of operation, more than one generation. Therefore, designers must include in the project the the maximum amount of strength, reliability, and survivability, regardless of the cost parameters. The main priority of the NPP design is their safety. According to the assessment made by SC "Rosatom", about 40% of the unit cost is the cost of the

security systems. The disadvantages of choosing the design values of external influences related to the lack of knowledge of the probabilistic behavior of a tsunami should be noted. Today, due to the climate change, the sea level raises making nuclear power plants in coastal areas even more vulnerable. The share of the security systems cost will grow with the installation of molten core catchers and additional post-fukushima systems [10].

Accidents at nuclear facilities tend to occur suddenly and have drastic consequences of a planetary scale. Any state alone is not able to fully and promptly eliminate the consequences of the accident at the nuclear power plant. It is necessary to join forces and resources of the various countries to address safe operation of nuclear power facilities. This requires the timely submission of reliable information in full, and to develop a unified concept of the accident constituencies liquidation.

In the negotiations of the IAEA with Japan, the issue of the invitation of Russian specialists with experience of liquidation of the Chernobyl accident to the "Fukushima" was raised, but the Japanese side refused this. The Japanese have not studied the Chernobyl experience, being absolutely certain of the impossibility of the accident at Japanese nuclear power plants.

The magnitude and frequency of technogenic disasters occurring in the world of indicate the significantly increased role of technical specialists. Sophisticated technological systems require strict compliance with technologies and regulations. The quality of training for the maintenance of such systems, as well as disaster recovery must be raised to the level corresponding to the complexity of the facilities created in the XXI century. In order to make informed decisions in the short terms and improve the effectiveness of measures to eliminate the consequences of the accident at the nuclear power plant it is necessary in advance to simulate the likely scenario of the accident, taking into account the impact, of the maximum possible number of favorable factors of the accident. And on the basis of modeling, to develop algorithms of actions to eliminate the consequences of the accident for a particular nuclear facility.

The cause of many serious accidents of the recent decades is bad practice of appointments to the senior engineering positions "universal" managers who are unable to adequately assess the situation and take responsibility for the actions to eliminate the emergency situation because of the lack of relevant knowledge and expertise. So, for

example, when the military diesel generators with non-standard connectors were delivered to the station and instead of connections of the diesel generators on a contingency scheme, they were sent back, which led to further loss of time.

An important factor in accident prevention and management is trained personnel. Operators of "Fukushima-1" nuclear power plant could not solve the problem of the accident localization. The operating personnel did not take their own decisions. Each operator according to the instructions should report the situation to their superior and etc. in chain order.

To ensure the safety of nuclear power plants, it is necessary to introduce the reactor cooling system functioning on the basis of natural physical principles (heat removal system by gravity, natural circulation), operating without the intervention of an operator and in the absence of the main and emergency power supply. It requires the introduction of the backup reactors cooling systems and their protective enclosures, the functioning of which is possible in the autonomous mode.

Inadequate reflection of the events occurred as a result of the accident and its subsequent liquidation by the authorities and the media do not allow experts to analyze the situation and provide timely support for the rapid elimination of consequences of the accident. The explanations provided by the authorities about the causes of failure of reactor emergency cooling down system was not clear (a reference to the tsunami exceeded the height of beyond design basis).

The explosion of mixture of hydrogen and air destroyed containment vessel, whereby it was not possible to hold the radioactive substance inside. Thus the third pillar of security was violated effecting the environment, - holding of the radioactive substances in the containment.

According to official data, 13 diesel generators with fuel tanks were washed away by a wave. But according to the project, diesel generators are located in the basement of the reactor building. Additional mobile diesel generators not the main ones were washed away. It has been reported that shortly before the accident, diesel generators at the "Fukushima-1" plant were replaced by gas generators, supply of which with gas was carried out centrally.

First days of disaster showed all the reactor facility design flaws and mistakes made by the operating organization. But the main mistake was the high vulnerability of emergency power supply systems and seawater intake system. As per the de-

sign, if the limit pressure is exceeded the safety valve shall be actuated, and the steam from the reactor vessel shall be bleed into the outer casing – containment. The strength of the containment was inadequate; therefore, a hydrogen-steam mixture was released into the reactor building. After redeveloping in 1992, reactors of this type were supposed to have ventilation line for pressure relief of torus outside the building. But during the disaster hydrogen inexplicably was not outside, but in the reactor buildings as a result of such ventilation.

The conclusions of the disaster relate to various aspects of nuclear power plant operation.

Russia, France and the USA established organizations with sufficient technical resources and qualified personnel, which can be immediately delivered to any damaged power unit for the implementation of adequate measures to address an emergency situation.

In June 2011, the IAEA Conference on nuclear safety has considered and approved a plan of actions on nuclear safety. The EU decided that all plants shall be subject to additional inspection. The decision to conduct stress tests was unanimously adopted by the EU countries in March, 2011 after Fukushima Daiichi nuclear disaster. During April and May the European expert group of regulators in the field of nuclear safety ENSREG coordinated the methodology and criteria of the stress tests, which were to submit a full safety analysis of operating and projected nuclear power plants. The volume and content of the analyses have been determined by Western European Nuclear Regulators Association (WENRA), i.e., the organization, which combines supervisory authorities of European countries. Rostekhnadzor, which is not part of this Association, regularly participates in all its meetings as an associate member.

Nuclear infrastructure of Europe (143 nuclear power plants), which produces a third of EU electricity consumption, has undergone a strict check on the stability in the event of disasters (stress tests) from an earthquake to a fall of heavy aircraft. Stress tests of European nuclear power plants were carried out in three stages: directly by operators of nuclear power plants, by national nuclear agencies and experts from the European Commission and Council of the European Union.

Worst-case scenarios, their combination and the possibility of plant personnel and local emergency services to response these emergencies have been analyzed. According to the results of stress tests, it was agreed to strengthen the security re-

quirements that must be implemented always and everywhere [10].

In 2012, in the Russian Federation all nuclear power plants were equipped with additional mobile diesel generators 0.4 kW and 6 kW, protected against extreme external influences (including fuel tanks), allows for long-term maintenance of nuclear power units in safe condition in full-de-energizing of the NPP; all nuclear power units are equipped with diesel pumps and motor pumps for the organization of abnormal water supply for cores, steam generators, spent fuel pools cooling.

Equipping of all nuclear power units with hydrogen recombiners and systems of control of gas concentration, which form a combustible medium will be fulfilled by 2016. In case of nuclear power unit blackout and impossibility of voltage supply from the regular power supply systems, voltage will be supplied from the mobile emergency diesel generator station (MEDGS), which allows auxiliaries electric power supply through pre-laid cable passages, or by laying of cables available on MEDGS. Fuel reserve is rated for 10 days of PADGS operation. In addition to the additional diesel generators, each unit is equipped with accumulator batteries, placed in a secure room. Battery capacity provides their operation during 10 hours; this equipment is installed on each unit.

In the case of beyond-design-basis accident involving loss of feed water, power units have standalone feed water supply system using a mobile pumping unit (MPU) with an independent diesel drive. MPU is fully autonomous; fuel reserve is rated for 24 hours operation.

Nevertheless, “Post-Fukushima syndrome” affected the global nuclear power industry. At the time of Fukushima Daiichi nuclear disaster (11.03.2011) 448 units with rated capacity of 380 280 MW (el.) were operated in the world. Currently, there are 438 operating reactors. This number includes 51 Japanese units, which had been temporarily stopped to check their safety. All reactors of “Fukushima-1” NPP will not be energized. The current state of nuclear power (as of 01/20/2014 was) can be represented by the following figures: 438 operating units, the rated capacity is 374332 MW (el.); 64 of them is over 40 years, the rated capacity is 39091 MW (el.); 84 BWR-type reactors (boiling-water reactors), the rated capacity is 78046 MW (el.); 71 units under construction, the rated capacity is 70612 MW (el.) (Fig. 2).

Currently, the age of the bulk of the operating units is about 30 years.

Fig. 2. The number of units put into in the global nuclear power industry at different years

After Fukushima Daiichi nuclear disaster, different countries pursued different policies in respect of nuclear power industry. In Germany, 8 units were stopped, all 17 reactors that provide 26% of electricity will be stopped by 2022. In Switzerland, all the units will be stopped with the exhaust of their performance potential. The last unit must be stopped in 2034, but that decision has not yet been approved by Parliament and may be reconsidered in the future. According to the poll, which was hold in the autumn of 2013, the majority of the Swiss population was in favor of nuclear energy. Citizens believe that if nuclear power plants are safe (there are five nuclear power plants in Switzerland), then they can continue to work. Italy has stopped all its units as far back as 1988 after the Chernobyl disaster, but planning to develop nuclear energy, forewent it. Spain, Venezuela, the Philippines, Israel, Morocco, Tunisia, Uruguay, Kuwait refused the use of nuclear energy.

A number of countries have postponed a decision on the development of nuclear energy. Thus, Belgium, in which more than 50% of electricity is generated by nuclear plants, has not yet made a decision. Thailand planing the development of nuclear power, postponed the implementation of these intentions till things go better.

Most of the countries (USA, UK, Russia, China, France, Belarus, Turkey, Vietnam, Bangladesh, Jor-

dan, UAE, Poland, Saudi Arabia, Egypt and others.) continued the policy of nuclear power development.

At the moment, nuclear energy has no serious alternatives. Furthermore, the strengthening of requirements for nuclear safety will inevitably lead to the decommissioning of the oldest stations (especially in Western Europe and the United States), which will require the construction of new facilities. According to the US Chamber of Commerce, the volume of the world market of nuclear products, services and fuel for the next 10 years will amount to 500-740 billion dollars. Now more than 60 power units is being built and more than 150 projects of new nuclear power plants are on the licensing stage and advanced stage of development worldwide.

4 units is currently build under the project "Generation 3+" (reactors with increased safety requirements). The remaining units are built under project of the 2+ and 3 generation. The only new project with the core catcher is a Russian reactor tank VVER-1200. Currently, two VVER-1000 unit with core catcher are operated at the Chinese station "Tianwan" and two in India at the NPP "Kudankulam". The first unit is put into operation at 75% capacity.

The rest of the specifications of the energy-generating units are about the same. South Korean APR-1400 reactor tank (two units with APR-1400 is being constructed at NPP "Shin-Kori"), the containment shell is single. The export version for the United Arab Emirates has a double shell (see table).

Russian projects are characterized by the presence of innovative technologies: it is the above is a core catcher in case of beyond design basis accidents; fully digital control system, including the nuclear power plant safety systems; double containment shell of the reactor building; main water lubricated circulation pumps; unparalleled range of diagnostics of the state of basic equipment and metal of NPP; capacity of power unit to operate in the daily load control mode etc.

Reactors of the III generation

Reactor (country-designer)	Protection against external impact	Containment shell of the reactor hall	SPOT availability	Molten core catcher availability
BBOP-1200 (Russia)	+	Double	+	+
EPR-1600 (France)	+	Double	+	—
AP-1000 (USA)	+	Double	+	—
APR-1400 (Korea)	+	Ordinary (Double for export)	+	—

For the second time after the Chernobyl accident, the nuclear power faces the threat of outbreaks of mistrust of the world community to nuclear technology. In order to restore positive momentum of development of nuclear power shall undergo a big explanatory work among the population, experts and politicians. The Japanese tragedy is the opportunity for a sober assessment of the risks and to abandon savings on security.

Analysis of the energy security of the world confirms that nuclear power is an essential component of the global power balance, without which humanity cannot do, and it is equivalent replacement has not been found. The absolute majority of the countries decided to continue the

development of nuclear energy. The key issue of nuclear power development is its security, so the security requirements for nuclear power plants are dramatically tightened around the world, which must be carried out always and everywhere.

Hopefully, the lessons learned will be used for the benefit of mankind. Nuclear reactors will be much more reliable and safer. Our main duty is to learn from the accident at the "Fukushima-1" all the useful lessons and apply their knowledge to practice with the main goal - minimizing the risk to life and health of present and future generations of inhabitants of the planet.

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