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FUKUSHIMA - DESCRIPTION OF THE ACCIDENT AND ENVIRONMENTAL CONSEQUENCES

Abstract: *As it is well known, a large scale nuclear accident occurred in the nuclear power plant Fukushima in Japan. The main cause was large water wave, "tsunami" followed by a strong earthquake. All nuclear reactors in Fukushima Daiichi power plant were involved in the accident. Pools with nuclear waste were also damaged. In this paper, the nuclear accident in Fukushima was described in details. Due to this accident, some amount of radioactive material was released in the environment, which caused severe contamination of air, ocean water and neighbouring land. Contamination level in Europe due to Fukushima accident was discussed in more detail. A review of published data about contamination was also presented.*

Key words: Fukushima, nuclear accident, environmental pollution.

DESCRIPTION OF THE ACCIDENT

On 11.03.2011, a large scale tsunami, followed after a strong earthquake of M=9 overflow the nuclear power plant Fukushima Daiichi. The earthquake occurred under the sea, about 70 km eastern of Oshika peninsula, at the depth of about 32 km. It was the most powerful earthquake that had ever hit Japan, and the fifth strongest in the world, since the official modern record has begun in 1900. This earthquake triggered mega tsunami which wave reached up to 40 m in Iwate prefecture. The wave height was smaller on other locations, being about 8 m in Fukushima area. Japanese authorities reported 15,854 people dead, and 3,155 missing people. In addition, about 27,000 people were injured.

Fukushima Daiichi plant was comprised of six separate nuclear reactors. All reactors were water boiled type, maintained by Tokyo Electric Power Company TEPCO. At the time of the quake, the reactor 4 had been de-fueled, while the reactors 5 and 6 were in cold shutdown for planned regular maintenance. The remaining reactors shut down automatically after the earthquake, and emergency generators started up to run the control electronics and water pumps needed to cool them. The plant was protected by a seawall protection designed to withstand a 5.7 m tsunami. However, the 14-metre tsunami wave arrived 15 minutes after the earthquake. The entire plant was flooded including low-lying generators and electrical switchgear in the reactor basements, whereas its connection to the electric grid was broken. There were three independent cooling systems, but all of them failed. All power for cooling was lost and reactors started to overheat, despite shutdown, due to natural decay of the fission products created before shutdown. Generally, it is worth mentioning that about 6 % of total fission energy is released through beta and gamma decay of fission products. It amounts up to 12 MeV per fission. This

energy is then transformed into the heat, and although the chain reaction is stopped, it is necessary to cool down the reactor core, until the radioactivity decreases significantly below a certain level. It is similar for spent fuel pools which must be cooled down for some period of time. The radioactivity of short lived fission product decreases with the time in a complicated manner. Since the cooling system was broken, the overheating of the reactor core and the spent fuel started. Soon after the tsunami, the evidence arose of partial core meltdown in the reactors 1, 2, and 3. At high temperature, **water vapour usually interacts with zirconium** which is used in construction elements, taking the oxygen atom from H₂O. In this way, the large amount of hydrogen remained within the reactor. This hydrogen exploded and destroyed the upper cladding of the buildings housing reactors 1, 3, and 4. An explosion damaged the containment inside the reactor 2, whereas multiple fires broke out at the reactor 4. In addition, spent fuel rods stored in spent fuel pools of units 1–4 began to overheat because of constant production of heat, as water levels in the pools dropped. Fears of radiation leaks led to a 20-kilometre radius evacuation around the plant, while workers suffered radiation exposure and were temporarily evacuated at various times. One generator at unit 6 was restarted on 17 March allowing some cooling at units 5 and 6 which were least damaged. Grid power was restored to parts of the plant from 20 March, but machinery for reactors 1–4 damaged by floods, fires and explosions remained inoperable. Japanese officials initially assessed the accident as level 4 on the International Nuclear Event Scale (INES) despite the views of other international agencies that it should have been higher. The level of accident was raised successively to 5 and then the maximum 7 (according to international scale). Whole situation is more complex that it could be described here.



Figure 1. The roof of Unit 3 demolished by hydrogen explosion (left part) and Unit 4 damaged by this explosion (right part). The photo was taken on 28.02.2012.

Managing the problem

The main problem was to enable cooling of all damaged reactors and spent fuel pools. All work on damaged reactors was seriously hindered by high level of radiation within reactors building and around them. It was reported that the dose was up to 400 mSv/h at some position within the power plant. In Units 1, 2 and 3, fresh water was continuously injected both via the feed water system lines and the fire extinguishers lines into the reactor pressure vessel; temperatures and pressures were stabilized. To protect against potential damage of the future earthquakes, TEPCO started work on 9 May of 2011 to install a supporting structure for the floor of the spent fuel pool of Unit 4. TEPCO formulated the hypothesis that the damage to the Unit 4 building could have been caused by hydrogen generated at Unit 3 that flowed into Unit 4. Fresh water was injected into the spent fuel pools of Units 1 - 4. Water supply from pump trucks was being gradually replaced by the Fuel Pool Cooling and Clean-up system in Units 1 to 3. However, closed loop cooling has not been established for longer period of time. Stagnant water with high levels of radioactivity in the basement of the turbine buildings of Units 1 and 3 was being transferred to the condensers, the radioactive waste treatment facility, the high-temperature incinerator building and temporary storage tanks. Stagnant water in the basement of the turbine building of Unit 6 was being transferred to a temporary tank. Countermeasures against the outflow of water to the sea and to prevent and minimize the dispersion of radionuclides in water have been put in place.

Overall, the situation at the Fukushima Daiichi nuclear power plant remains very serious. TEPCO has planned to completely demolish four reactors in 30-40 years.

Radiation measurement

The daily monitoring of the deposition of cesium and iodine radionuclides for 47 prefectures was undertaken. Since 17 May, deposition of ^{131}I has not been observed. Low levels of ^{137}Cs deposition were reported in a few

prefectures on a few days since 18 May; the reported values range of from 2.2 to 91 Bq/m² for ^{137}Cs .

Gamma dose rates values for all 47 prefectures are reported daily by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) of Japan. On 31 May, the gamma dose rate reported for Fukushima prefecture was 1.5 $\mu\text{Sv/h}$. In all other prefectures, reported gamma dose rates were below 0.1 $\mu\text{Sv/h}$, with a general decreasing trend. Meanwhile, the decrease of the gamma dose rate has slowed down, since the short-lived radionuclides have decayed away.

Gamma dose rates reported specifically for the monitoring points in the eastern part of Fukushima prefecture, for distances of more than 30 km from the Fukushima Daiichi plant, showed a general decreasing trend, ranging from 0.1 $\mu\text{Sv/h}$ to 17 $\mu\text{Sv/h}$, as reported for 31 May.

On-site measurements at the west gate of the Fukushima Daiichi plant indicate the presence of ^{131}I and ^{137}Cs in the air in the close vicinity of the plant (within approximately 1 km). The concentrations in air reported for 29 May of 2011 were about 3 Bq/m³ for ^{131}I and about 9 Bq/m³ for ^{137}Cs . The values observed in the previous days showed daily fluctuations with an overall decreasing tendency.

Marine and seawater monitoring

The marine monitoring programme has been carried out both near the discharge areas of the Fukushima Daiichi plant by TEPCO at 22 locations and at off-shore stations by MEXT on 16 stations. The radioactive contamination of the marine environment had occurred by aerial deposition and by continuing discharges and outflow of water with various level of radioactivity from the four damaged reactors at Fukushima Daiichi.

The activity concentrations of ^{131}I , ^{134}Cs and ^{137}Cs in seawater close to the Fukushima Daiichi plant have been measured every day since 2 April. Concentrations of ^{134}Cs and ^{137}Cs decreased from more than 100 MBq/L initially to less than 5 kBq/L on 7 May, but increased again to levels of around 20 kBq/L at the 16 May and to about 10 kBq/L on the 17 May. Since then, the concentrations dropped slowly to less than 2 kBq/L, but increased to about 5 kBq/L on 29 May. The levels of ^{131}I are varying significantly and the activity ratio to radio-cesium is not constant. On 28 and 29 May, the concentrations were around 20 kBq/L. The variability of ^{131}I relatively to the radio-cesium concentrations could be an indication of retention of cesium by the zeolite sandbags in place, which would have almost no effect on iodine or further production of decay products in the reactor.

Monitoring of the marine environment is performed by TEPCO on the near field area and by MEXT at off-shore sampling positions. The monitoring of MEXT includes also measurement of ambient dose rate in air above the sea, the analysis of ambient dust above the sea, the analysis of surface samples of sea water and

the analysis of samples of sea water collected at 10 m above the sea bottom and in a mid-layer as well at a few locations for sediments. On most of the offshore stations ^{131}I , ^{134}Cs and ^{137}Cs reached the levels below the applied detection limit of 10 Bq/L. There will be a further decrease of the concentration during the propagation of contaminated waters in the sea. The activity found in surface sediments at the near shore stations close to the reactors was between 24 and 320 Bq/kg for ^{137}Cs in the middle of May. The activity in sediments decreases with distance, but is also highly dependent upon the sediment type. The contamination of marine sediments indicates the enrichment of radio-cesium on particulate matter and its removal from the water column into the sea floor.

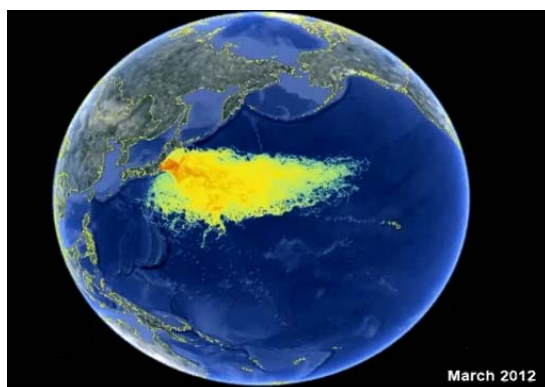


Figure 2. Contamination of Pacific Ocean sea water on March 2012 due to Fukushima Daiichi accident

Contamination of air and land

After the hydrogen explosion in unit 1 on 12 March, some radioactive cesium and iodine were detected in the vicinity of the plant. After that, ^{131}I and ^{137}Cs were apparently released during the following few days, particularly following the hydrogen explosion at unit 3 on 4 and the apparent rupture of suppression chamber of unit 2 on 15th. Considerable amounts of ^{133}Xe and ^{131}I were vented, but most of the ^{137}Cs (14 out of 15 PBq total) along with most of the ^{134}Cs apparently came from unit 2 on or after the 15th. Also, ten times higher concentration of iodine was attributed to unit 2 than unit 1, while unit 3 produced half as much as unit 1. However, there was some uncertainty about the exact sources and timings of the radioactive releases.

The French Institute for Radiological Protection & Nuclear Safety (IRSN) estimated that maximum external doses to people living around the plant were unlikely to exceed 30 mSv/yr in the first year. This was based on the airborne measurements between 30 March and 4 April, 2011. It compares with natural background levels mostly 2-3 mSv/yr. As a dose limit for general population, 1 mSv was recommended by ICRP and accepted by many countries. Also, it is comparable with the professional dose limit of 20 mSv/year.

The main concentration of radioactive pollution stretched northwest from the plant, and levels of ^{137}Cs

reached over 3 MBq/m² in soil here, out to 35 km away. In mid May, about 15,000 residents in a contaminated area 20-40 km northwest of the plant were evacuated, making a total of about 100,000 displaced persons.

CONTAMINATION OF THE REST OF THE WORLD

Recently, a number of papers have appeared in different journals and newspapers giving results of observed contamination in North America, Europe and Asia. A special issue of Journal of Environmental Radioactivity is being prepared at the moment.

Most of the results were obtained by filtering the large amount of air and measuring of activity collected on filters. In this way, certain amounts of ^{131}I , ^{137}I , ^{135}Cs were detected in North America, Europe and Central Asia. Some contaminations of snow and rain water were also observed. For example, the results by A. Bolsunovsky and D. Dementyev [1] on samples taken in Krasnoyarsk, (Central Asia) are presented in Table 1.

Table 1. Some results from Central Asia

Sample	^{131}I (Bq/l)	^{137}Cs (Bq/l)
Melted snow	0.39-0.63	0.24-0.75
Rain water	0.031-0.058	0.007

Contamination of air with fission products were also detected across Europe. For example, in Milano (Italy), radioactivity in air and rain water was measured starting from 31.03.2011 to 05.05.2011. Some representative data are given in Table 2.

Table 2. Radioactivity of air and rain water in Milano after Fukushima accident [2]

Date of sampling of air	^{131}I (mBq/m ³)	^{137}Cs (Bq/l)
31.03.2011	0.322	0.029
03.04.2011	0.467	0.040
28.04.2011	0.06	0.023
Date of sampling of rain water	^{131}I (mBq/L)	^{137}Cs (Bq/l)
28.03.2011	891	122
12.04.2011	725	859
15.04.2011	291	45

Radioactivity contamination was also observed in Serbia. Concentration of ^{131}I in air was up to 2.7 mBq/m³ [5].

DOSES

The committed equivalent dose for the thyroid due to inhalation of ^{131}I is calculated, taking into account the contamination level, duration of exposure and conversion factor. Using the parameter values given by the IAEA (2000; p.109) ^{131}I , 23 mBq d/m³, leads to **0.13 and 0.23 μSv** for adults and children, respectively.

Including gaseous iodine multiplies this dose by a value of about 4; the highest thyroid doses should thus probably be in the order of 1 μSv .

Activity of ^{131}I in rain water in France in period March-April 2011 reached 3.5 Bq/L (Perrot et al. JER).

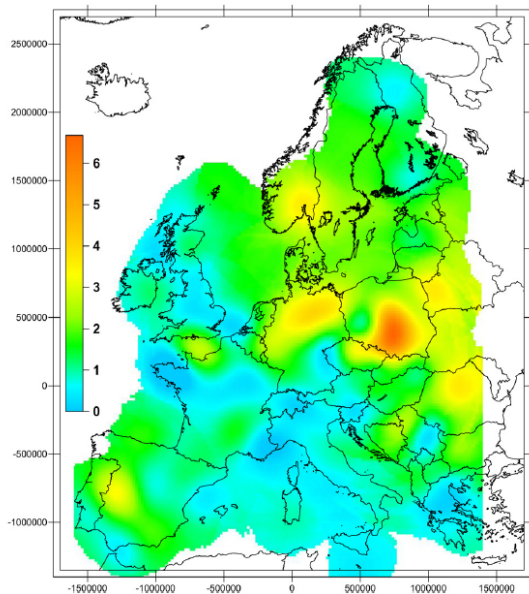


Figure 3. ^{131}I contamination of Europe. Estimated distribution of maximum ^{131}I (particulate) concentration over Europe. Scale unit: mBq/m^3 . Axis units: m. (Bosew et al. JER 2012) [3],[4]

CONCLUSION

Doses estimated in Europe are very low, and they are of order μSv . For the sake of comparison, we have cited dose limits for general population which is established at 1 mSv/year.

This event will influence the future construction of Nuclear Power plant. Better planning is necessary to prevent possible accidents caused by natural events, such as earthquakes, hurricanes, flooding and other.

Although the world has already encountered several serious nuclear accidents, there is still a strong necessity for this source of energy, and in my opinion, the construction of new nuclear power plant is unavoidable.

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BIOGRAPHY

Dragoslav Nikezić was born on 25.11.1953. in Aleksinac. He graduated from the Faculty of Philosophy, Physics Department, University of Niš, in 1976. He obtained his Ph.D. in radiation and nuclear physics at University of Kragujevac, in



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FUKUSHIMA, OPIS AKCIDENTA I POSLEDICE PO OKOLINU

Dragoslav Nikezić

Rezime: Kao što je poznato veliki nuklearni akcident se dogodio u nuklearnoj elektrani Fukushima u Japanu. Akcident je izazvan velikim cunamijem koji je pratio zemljotes. Svi reaktori u elektrani Fukushima su na neki način pogodjeni i učestvovali u ovom akcidentu. Bazeni sa istrošenim nuklearnim gorivom su takodje pretrpeli oštećenja. U ovom radu nuklearni akcident je detaljno opisan. Izvesna količina radioaktivnog materijala je ispuštena u okolinu što je izazvalo ozbiljnu kontaminaciju vazduha, vode okeana i tla u okolini elektrane. Nivoi kontaminacije u Evropi usled akcidenta u Fukushimi su dati sa iazvesnim detaljima. Pregled publikovanih podataka o kontaminaciji je takodje predstavljen.

Ključne reči: Fukushima, nuklearni akcident, kontaminacija životne sredine.