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VARIA

The nuclear accident at Chernobyl: Immediate and further consequences

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Abstract: *The accident at Chernobyl occurred in April 1986 at the Chernobyl Nuclear Power Plant in Soviet Union. The incident occurred during a scheduled safety test. A combination of inherent reactor design flaws and operators' mistakes resulted in reactor's No.4 disaster and the emission of a large quantity of radiation. The immediate actions involved the fire extinguishing, the cleanup of radioactive residues and the prevention of a new explosion. For this purpose, plenty of people worked with self-sacrifice. The people who lived nearby were removed. As far as the socio-economic impact for the Soviet Union is concerned, it was quite serious. Moreover, the environmental and human health consequences were also alarming with thyroid cancer being the most studied. Useful conclusions, especially for the safety both of reactors and nuclear power, as well as for the impact of radiation at ecosystems have been drawn. The debate about the use of nuclear power has remained open ever since.*

Keywords: *nuclear power, thyroid cancer, RBMK reactor, radiation, radioactivity, liquidators*

INTRODUCTION

The Chernobyl nuclear accident occurred on 26 April 1986 in the light water graphite moderated reactor No 4 at the Chernobyl Nuclear Power Plant, close the town of Pripyat, in Ukrainian Soviet Socialist Republic Soviet Union, roughly 100km of the city of Kiev [1].

The reactor exploded during a safety test that was inappropriately made, with the operators losing control. This was due to a design defect of the RBMK reactor, which made it unstable when performed at low power. The outcome was the destruction of the reactor and the leakage of a huge amount of radiation into the environment [2, 3].

During the accident two deaths were caused because of explosion. Over the coming weeks a number of emergency staff was hospitalized with acute radiation sickness (ARS), while 28 firemen and employees finally died. The Chernobyl accident is considered the most damaging nuclear power plant accident in history. The Chernobyl and the Fukushima accident are the two nuclear accidents classified as a level 7 (the maximum classification) on the International Nuclear Event Scale [4].

CHRONOLOGY

The city of Chernobyl is located in Ukraine at a distance of 104km northeast of Kiev and 16km from the border with Belarus. Before the evacuation, it had about 14,000 inhabitants. Closer to the plant was the larger city Pripyat (about 49,000), which was built to accommodate the employees of the nuclear plant and their families [1]. The Chernobyl Nuclear Power Plant began to operate in 1977 with the first reactor of a total of four. Gradually, three more

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reactors began to operate by 1983. They were boiling water reactors with enriched uranium, type RBMK. The plant had a total capacity of 4000 MW electric power. The combination of graphite as a moderator and water as coolant is not found in other types of reactors [5].

THE ACCIDENT

When the reactor operates, it has an integrated cooling system. When it is shut down, the radioactive decay continues and heating of the reactor continues too. As a result, further cooling is required even after the reactor has been switched off. However, the three diesel engines which were used for this purpose needed 60-75 sec interval to achieve the required performance. In case of emergency, the reactor would be left without adequate cooling for this period, which was a very serious risk [6]. To remedy this problem, it was suggested the use of the kinetic energy of the steam turbine which was produced during the deactivation of the reactor.

After three failed tests (1982, 1984 and 1985) and some changes in design, a new test was designed to become in April 1986, when the Reactor No 4 was deactivated for scheduled maintenance. The test ended up in the tragic accident that occurred in 01:26 on Saturday, April 26, 1986. After a sequence of events during the test (which are not relevant to the present paper) it finally resulted in an uncontrolled increase of power. Simultaneously, the steam pressure in the reactor increased which eventually led to the first burst. The reactor's building was destroyed and a significant amount of radioactive materials were released into the atmosphere. A few seconds later, a second stronger explosion followed. Several fires broke out while the reactor itself started to flare [7].

Causes of the accident

The accident at Chernobyl was the result of a combination of unauthorized manipulations, human errors and design imperfections of the type RBMK reactor. According to the reappraisal of the accident by International Nuclear Safety Advisory Group at 1997 [8] the factors that contributed were:

- Unlike to most nuclear reactors which have a negative void coefficient, the RBMK had a dangerously high positive void coefficient.
- The use of graphite at the end of the control bars resulted in lowering the reactor power, had as a result the reactor power to be increased for a few seconds. This behavior is counter-intuitive and was not known to the reactor operators.
- The design of RBMK reactor had also other defects and was not consistent with the minimum acceptable safety rules for nuclear reactors.
- There was deficient safety culture in the design, organization and operation of nuclear power by the Soviet Union.
- There was inefficient and inadequate transmission of important information, both between operators and between operators and designers.
- There was inadequate safety analysis.
- The test was scheduled to take place before the night shift from well informed and familiar with the process employees. However, due to an unexpected ten-hour delay, the test was made during the night from less experienced staff.

The first hours

During the accident two workers were killed because of the explosion. There have been many fire focuses, the main of them were on the roof of the station and the reactor No 4. Initially, firemen were unaware of the risk of smoke and debris and did not receive any additional protection measures. So they received high doses of radioactivity. Although the fire on the roof had extinguished until 05:00 o'clock, the fire inside the reactor was still active. Within the next few days about 5,000 tons of chemical materials and sand were thrown by military helicopters to absorb the radiation.

The levels of radioactivity reached 20.000 Roentgens (R) per hour (the leather dose is 500R within 5 hours). In the first hours, both workers and supervisors in the control room were unaware of the actual levels of radioactivity. The one dosimeter did not work and the second one was not accessible due to the explosion. The remaining dosimeters had a measurement limit of 0,001R/s, so they showed "off scale" [9]. Due to faulty readings, the head of the station, Alexander Akimov, believed that the reactor was not affected by the explosions. Akimov and his assistants remained in the reactor building until the morning without taking any protection measures. Most of them, including the Akimov, died from exposure to radiation within the next three weeks.

IMMEDIATE CONSEQUENCES – CRISIS MANAGEMENT

After the extinguishing of fireplaces, a number of problems and potential risks had to be addressed:

I. Steam explosion risk

The floors under the reactor were filled with water. At the same time, smoldering graphite, fuel and other materials fed to the reactor began to mix with molten concrete from the

reactor walls resulting in a semi-liquid material that resembled a lava [10]. If this mixture succeeded in penetrating the reactor floor and coming into contact with water, it could cause a more disastrous explosion. To prevent this danger it was considered necessary the water pools to be drained. This hazardous mission was carried out by engineers Alexei Ananenko and Valeri Bezpalov and the shift supervisor Baris Baranov. After the valves had been opened a large amount of extremely radioactive water was pumped.

II. Radioactive debris removal

The next challenge was the removal of the radioactive particles which were dispersed around. The main part of this effort shouldered the army. The plan included the transport and disposal of radioactive materials within the reactor core. Wearing lead protective clothing, the "liquidators", as the workers were called, either transplanted radioactive materials manually, or handled heavy machines which did the same job. Many of them received cumulatively high doses of radiation throughout the procedure [11]. Furthermore, a large number of remote-controlled machines were used in order to be avoided the exposure of workers to high doses of radioactivity.

III. Announcement of the accident

At 21:02 on 28 April, about 67 hours after the accident, a 20-second announcement was read on a TV news program: "There has been an accident at the Chernobyl Nuclear Power Plant. One of the nuclear reactors was damaged. The effects of the accident are being remedied. Assistance has been provided for any affected people. An investigative commission has been set up". However, attempting not to hurt the prestige of the regime, the Soviet authorities initially had tried to hide the incident. The above announcement occurred only when the morning of the 28 April, in routine control, personnel of the Swedish Nuclear Power Plant at Fosmark recorded high levels of radioactivity. The Swedish government came into contact with the Soviet Union and the latter was forced to admit that an accident had occurred [12]. Although, the Soviet government, attempting to downplay the event, issued a statement that there was no reason to postpone the celebrations and parade for the 1 May International Worker's Day in Kiev.

IV. Evacuation of Pripyat

After the incident, the residents of Pripyat, completely ignored what had happened. A special committee was created a few hours later to investigate the accident. The committee arrived at the plant on the afternoon of April 27 and soon had enough evidence of the seriousness of the situation seriousness. So, in the early hours of April 27, 36 hours after the accident, they decided to evacuate Pripyat. It was initially decided that the evacuation would only be for 3 days but shortly was decided the permanent implementation of this measure.

With a statement issued by the city council the residents were informed that they would displace the city for 3 days by buses started at 14:00, on 27 April. The evacuation would be under the supervision of the police and the city officials. The residents had also been informed to take with them only their documents and entirely essential personal belongings. It was also announced that all assets would be kept by the police after the evacuation. Except for the police officers who would remain in the city for safety, there was a list of employees who were required to remain for the continuity of the plant operation. Around 15:00 a total of about 45.000 residents were transferred to different villages in the Kiev region [12].

V. Set up of exclusion zone

On May 2, a government committee decided –rather arbitrarily- a 30km area from the damaged reactor as the designated evacuation zone. This area was also divided into three sub-zones in which, both the protection measures of those who arrived, and the activities which took place, were different: The area around the reactor, a second with a radius of about 10km, and the rest zone until the 30km.

Later, this distinction was made according to the revised dose limit of 100mSv [13]. So there were:

- the "Black Zone" (over 200 μsv/h)
- the "Red Zone" (50-200 μsv/h)
- the "Blue Zone" (30-50 μsv/h)

In the first place the inhabitants would never return. In the second they may be back when the radiation levels would be reduced. In the third only children and pregnant women would have to be removed. Although the evacuation of these areas was not immediate, a total of 116,000 people were eventually removed. However, there were few residents, mainly elderly, who refused to remove. After repeated efforts at expulsion, authorities finally accepted their presence giving them an unofficial permission to stay.

The boundaries and the status of the zone and sub-zones have been amended many times in the coming years.

FURTHER CONSEQUENCES

I. Financial consequences

It is very difficult to determine the total cost of the Chernobyl accident. It afflicted, and continues to, both the Soviet Union

(and the countries which have arisen since its breakup), and many other countries. According to the Chernobyl Forum Report (2005) the 22% of the national budget of Belarus in 1991 was connected to Chernobyl (decreased at 6% in 2002), while in Ukraine 5-7% of the government spending continues to be related to the accident [14]. A great part of the cost is still about Chernobyl-related social benefits in approximately seven million people in Russian, Ukrainian and Belarus. Another important economic factor for the years after the accident was the removal of 1,900,000 acres of agriculture land, as well as 1,700,000 acres of forest from production.

Finally, a large number of countries, mainly Europeans, have been forced to spend resources to check the amount of radioactivity in soils, food and water, while International Organizations, such as the World Bank, have financed both the rehabilitation work and the building of the new reactor shelter (New Safe Confinement).

II. Political and social consequences.

Before the accident M. Gorbachev had implemented the political "glasnost" with purpose to enhance the transparency of politics. However, the accident led to return to past secretive politics. At the same time, distrust of international community against the Soviet regime was grown up. The mistrust of the citizens towards the regime was also high enough, especially among nearby areas residents and those who needed to move.

Combined with the economic consequences, the lack of confidence, both in international and national level, is believed to have contributed to the fall of the Soviet Union, a few years later. Apparently, except for economic impact, political and social consequences continued to affect the 3 countries in this region, even the fall of the Union [14]. On the other hand, the need for bio-scientific cooperation helped forge closer relationship between Soviet Union and US at the end of the Cold War.

III. Environmental effects:

a) Spread of radioactive substances

It is estimated that Chernobyl released about four times the amount of radioactivity of the two atomic bombs in Hiroshima and Nagasaki. More than 100,000 km^2 were significantly contaminated even though the areas around the plant were the most overburdened. Lower levels of radiation were detected in different regions in Europe. The radioactivity dispersion was incongruous since it depended on both weather conditions and water paths. Soviet and Western scientists claim that 60% of radioactivity contaminated Belarus. Also, according to the 2006 TORCH report, half of the volatile particles came out of the Soviet Union [15].

b) Residual radioactivity

The Chernobyl Nuclear Power Plant is located next to the river Pripyat, which at that time was watering the broader area of Kiev. Although water purification measures were initially taken, the supply of water to Kiev began to become from the river Desna, two months later. Also, in some lakes in Russia and Belarus the concentrations of radioactivity in certain species of fish far exceeded the acceptable limits, even the period 1990-1992 [16]. On the contrary, excluding the exclusion zone, the groundwater does not seem to be affected.

c) Flora and fauna

After the accident, 4 km^2 of the neighboring pine trees were died, giving a characteristic red color that gave the name of the "Red Forest". Several of the wild animals in the most affected areas, either died or stopped breeding (most of the domestic animal in exclusion zone were removed) [17]. A typical example was the animals of a small island in the river Pripyat, where, the horses died and the beasts either died or were extremely weak. All of them due to significant thyroid malfunction.

In the following years, increased levels of radioactivity were detected in domestic animals both inside and outside of the Soviet Union. Several European countries have carried out checks on animal products in order to ensure consumer safety, for many years after the accident. As reported, were contaminated in total over 19.000 km^2 of agriculture land. Of these 2.640 km^2 will never be cultivated. Also about 17.000 km^2 of forest, mainly in the Ukrainian lands, were infected [14].

IV. Human impact

a) General

After the accident, totally 273 people suffered from acute radiation sickness, 31 of whom were died within the next three months. According to the Chernobyl Forum Report (2005), 28 of the "liquidators" died of Acute Radiation Syndrome, while 15 died of thyroid cancer within the coming years [14].

The same report states that it is extremely difficult to be calculated the total number of cancer due to the Chernobyl accident. The four most harmful radionuclides spread from Chernobyl were iodine-131 (half-lives: 8.02 days), caesium-134 (2.07 years), strontium-90 (28.8 years) and caesium-137 (30.2 years). Iodine, despite the small half-life, is the most unstable and appears to have caused the most important

health problems up to now [18]. It tends to become concentrated in thyroid and milk glands and cause thyroid cancer. Caesium tends to accumulate in vital organs such as the heart. Finally, strontium accumulates in bones increasing the risk of cancer.

According to WHO and independent researchers who studied the children of emergency workers, there was no statistically significant difference in mutation frequencies among children conceived before and after their father's exposure [19]. However, due to fear, distrust to the authorities and poor media information, an increase in the number of abortions in -other normal- pregnancies has been observed in some European countries. In Greece, although radioactivity measurements did not exceed the safety limits, there was an observed 2,500 excess of otherwise wanted pregnancies being terminated [20]. Furthermore, in countries such as Sweden and Finland, where there were not noticed more abortions, there was not increase in the incidence of congenital malformations [21]. The same conclusion is reached by Frank Castranovo study, of the Harvard Medical School in 1999, which has, among other things, analyzed the data from the two largest maternity clinics in Kiev [22]. He says that there is no evidence that the accident has increased the rate of birth defects.

b) Cancer assessments

The estimates of the number of cancers that have occurred or will arise in the future as a result of the accident vary enormously. This is due to both the lack of solid scientific data and the different methodologies used to quantify mortality. The Chernobyl Forum predicts that the total number of deaths could reach 4,000. However, these deaths are expected to be mainly among the most exposed people (emergency workers, evacuees, residents of the most contaminated areas) [14]. The Risk Projection suggests that Chernobyl can be responsible for about 1,000 cases of thyroid cancer and about 4,000 cases of other cancer, in Europe (0.01% of all cancer after the accident) but, as stated, the estimates are subjective. The most tightly associated with the accident cancer is thyroid cancer, due to the well-documented influence of the iodine on this gland.

According to the Forum, thyroid cancer is one of the main health impacts from the Chernobyl. On the contrary there has not been evidence for an increase of the number of other kinds of cancer or leukemia. The United Nations Scientific Committee on the Effects of Atomic Radiation ends up to similar conclusion. It finds an increase in the incidence of thyroid cancer, particularly among children and adolescents exposed to radiation, but no other indications of major health impacts [23].

Finally, the International Atomic Energy Agency indicates that there has been no increase in the incidence of solid cancer as a consequence of Chernobyl accident [14]. On the contrary, there are estimates such as the International Physicians for the Prevention of Nuclear War that refers to about 10.000 cases of thyroid cancer and 50.000 cases which are expected in the future [24].

c) Health disorders

One other important impact of the accident, especially among the directly involved populations, has to do with mental health. Both the incident itself and the initial attempt to be downgraded it had as a result to create exaggerated fears about the risks of radiation exposure. The IAEA supports that the designation of the affected people as "victims" rather than "survivors" has fed them to perceive themselves as weak, helpless and lacking control over their future [14]. Further health effects may have been caused due to this belief.

Other surveys show that humans remain largely unsure of what the effects of radiation actually are. For example, some teenagers or young adults who had received modest or small amount of radiation feel condemned to be ill and thus believe that there is no downside to have unprotected sex or use drugs.

The research and assessment of long-term effects of radiation on human health are continuous by many organizations, such as the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) [25].

DISCUSSION

The review of the causes and consequences of the Chernobyl accident had as a result many important conclusions to have drawn and, at the same time, there was a matter of intense concern.

The weaknesses and pathogens of the Soviet regime were clearly showed up. The authorities initially tried to conceal and then to devalue the gravity of the incident. For this reason, the decision to evacuate the much burden areas was delayed. This has resulted in the distrust and dispute of the citizens towards the authorities, which had as a result the citizens not to comply with the instructions of the following period.

Questions have also been raised about the safety, both the RBMK reactor and the nuclear reactors in general. The accident led to be made corrections to the design and operation of Soviet reactors but also of the reactor in West [26]. Simultaneously, a culture of safety was dealt with in the

handling of nuclear energy. The combination of reactor faulty manufacturers and human errors that led to the Chernobyl accident resulted in the persistence in safety of both governments and scientists as well as the leaders and staff of the nuclear power plants. A repetition of the Chernobyl accident is now virtually impossible, according to report of the German Nuclear Safety Agency [27].

Furthermore, cooperation between East and West has improved in terms of reactor improvement and safety. Since 1989 there have been many reciprocal visits from the former Soviet Union and the West. In 1989 the World Association of Nuclear Operators (WANO) was founded, which has under the auspices 130 operators of nuclear power plants in more than 30 countries [26].

The Chernobyl nuclear accident also helped to understand the impact of radiation on the environment, ecosystem and humans. Scientists had the opportunity to study short and long term radioactive contamination as well as to relate specific exposure levels with corresponding results. Also, knowledge and experience on the appropriate measures to protect against radioactivity have increased.

Despite the intense fear and concern it seems that the only sufficiently documented impact that accident had at the human health (excluding emergency workers who have received high doses of radiation during the first days from the accident) was thyroid cancer [28].

Finally, the debate on the use of nuclear energy remains open. There is a continuing dispute between those who argue that the use of nuclear power is dangerous, and those who claim it is necessary and sufficiently secure. The growing public awareness about climate change and the critical role that carbon dioxide and methane emissions play have increased the intensity of the debate. The use of nuclear energy is environmentally friendly and reduces fossil fuel consumption. However, if anything goes wrong the consequences can be devastating to humans and to the environment. The debate remains open today between those who fear the power of nuclear and those who fear what will happen to the planet if humanity does not use nuclear power.

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