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Multi-side Approach to the Realities of the Chernobyl NPP Accident

- Summing-up of the Consequences of the Accident Twenty Years After (II) -

チェルノブイリ原発事故の実相解明への多角的アプローチ

－ **20** 年を機会とする事故被害のまとめ **(II)** －

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Report of a research grant from the Toyota Foundation

(November 2004 – October 2006)

Project leader Imanaka T.

May 2008

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トヨタ財団助成研究

（2004 年 11 月～2006 年 10 月）

研究報告書（英語版）

研究代表者　今中哲二

2008年5月

Preface

This is the English version report of the international collaboration study, "Multi-side Approach to the Realities of the Chernobyl NPP Accident: Summing-up of the Consequences of the Accident Twenty Years" which was carried out in November 2004 – October 2006 supported by a research grant from the Toyota Foundation. Twenty three articles by authors of various professions are included about Chernobyl. The Japanese version was already published in August 2007, which contains 24 articles. (http://www.rri.kyoto-u.ac.jp/NSRG/tyt2004/CherTYT2004.htm) Out of them, 12 articles are included in both versions.

As a specialist of nuclear engineering, I have been investigating the Chernobyl accident since its beginning. Before the 20th anniversary of Chernobyl, I hoped to start a new project to try to make an overview of "Chernobyl disaster" by collecting various viewpoints of persons who have been involved in Chernobyl in their own ways: scientists, journalists, NGO activists, sufferers etc. I thought that a new image of Chernobyl could be constructed through learning different viewpoints. Fortunately the Toyota Foundation supported my proposal.

I think we could make a unique report about Chernobyl. In addition to this report, the following two reports were already published through the previous collaborations:

- Research Activities about the Radiological Consequences of the Chernobyl NPS Accident and Social Activities to Assist the Sufferers by the Accident. KURRI-KR-21, 1998.
  http://www.rri.kyoto-u.ac.jp/NSRG/reports/kr21/KURRI-KR-21.htm
- Recent Research Activities about the Chernobyl NPP Accident in Belarus, Ukraine and Russia. KURRI-KR-79, 2002
  http://www.rri.kyoto-u.ac.jp/NSRG/reports/kr79/KURRI-KR-79.htm

I wish all these reports will be useful to young people who want to know about Chernobyl as well as to the generation who experienced Chernobyl and are going to reconsider it again.

As the project leader, I would like to greatly appreciate authors of articles. At the same time, I express my deep apology for delaying the publication.

Imanaka T.
May 2008

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はじめに

本報告書は、「チェルノブイリ原発事故の実相解明への多角的アプローチ：20 年を機会とする事故被害のまとめ」というテーマで、2004 年から 2006 年にかけてトヨタ財団から研究助成をうけて実施した国際共同研究の英語版報告書である。日本語版報告書は、論文 24 編と付録 3 編をまとめて、すでに 2007 年 8 月に出版した（http://www.rri.kyoto-u.ac.jp/NSRG/tyt2004/CherTYT2004.htm）。本報告書には 23 編の論文が含まれているが、そのうち 12 編は日本語版に含まれている。つまり、11 編が新たな収録である。

国際共同研究の目的は、チェルノブイリ事故から 20 年になるのを機会に、専門的な枠を越え、ジャーナリスト、支援運動家などさまざまな人々の視点からみた「チェルノブイリ」をまとめてみることであった。さまざまな「チェルノブイリ」をいろいろなやり方で重ね合わせてみることによって、新たな「チェルノブイリ」が見えてくると考えたからである。この 20 年あまりの間にチェルノブイリ事故についてさまざまな報告が発表されているが、チェルノブイリ事故という巨大な厄災の全体を考えるうえで、我々の報告書はユニークなものに仕上がったと考えている。

今中らはこれまでにも、トヨタ財団や学術振興会からの研究助成をうけて国際共同研究を実施し、その成果を以下のような英文報告書にまとめている。

- チェルノブイリ原発事故影響研究と被災者救援の現状に関する調査報告
  KURRI-KR-21（1998 年 3 月）http://www.rri.kyoto-u.ac.jp/NSRG/reports/kr21/KURRI-KR-21.htm
- チェルノブイリ原発事故に関するベラルーシ、ウクライナ、ロシアでの最近の研究状況
  KURRI-KR-79（2002 年 7 月）http://www.rri.kyoto-u.ac.jp/NSRG/reports/kr79/KURRI-KR-79.htm

前者には 32 編、後者には 23 編の論文を収録してある。これらの報告書と合わせて、本報告書が、チェルノブイリ事故ひいては、原子力をエネルギー源とすることの意味を考える資料となれば幸いである。

研究助成を頂いたトヨタ財団ならびにお世話になった多くの方々に感謝するとともに、本報告書の出版が遅れたことをお詫びする。

2008 年 5 月　今中 哲二

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Many-sided Approach to the Realities of the Chernobyl NPP Accident
- Summing-up of the Consequences of the Accident Twenty Years After (II) -

チェルノブイリ原発事故の実相解明への多角的アプローチ
― 20 年を機会とする事故被害のまとめ (Ⅱ) ―

What Happened at That Time?

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✧ The eve

On April 25, 1986 (Fri), at the 4th block of the Chernobyl Nuclear Power Plant (NPP) in Ukrainian Republic of the former USSR, the procedure started to stop the reactor for maintenance for the first time since its operation in December 1983. At the Chernobyl NPP, four RBMK-1000 type reactors (1 GW electricity) were in operation and No. 5 and No. 6 blocks were under construction at that time.

It was in 1971 that a large project began to construct a nuclear power station on the bank of Pripyat river, a branch of Dnepr river, located about 100 km north from the Ukrainian capital, Kyiv (Fig. 1). In parallel with the power station, a new town named Pripyat city was constructed for station workers. The first block became in operation in 1977.

"RBMK" is an abbreviation of the Russian term meaning "Channel-type Big Power Reactor". From its structure, it can be called "graphite-moderator, light-water boiling, channel-type reactor" (Fig. 2. Table 1). RBMK was developed from the reactor originally constructed to produce plutonium for making Soviet atomic bombs. Its merits are the followings: refueling is possible while the reactor is in operation, power-upgrading is easy by attaching additional channels, inland construction is easy without difficulty of transporting heavy structures such as pressure vessel of light water reactor and so on. Meanwhile, the followings are its weak points: reactor control is complicated because of a lot of power channels (1,661 in the 4th block), vulnerable reactor characteristics that power will increase in a case of vapor increase at the reactor core (positive void reactivity coefficient), as well as power will surge in an extreme case that all control rods move down together into the core (positive scram). The last two design defects are considered directly related with the Chernobyl accident, but operators did not know such defects [1].

A emergency generator test was planned at the time of the shutdown of the 4th block on April 25. It was a test of a generator aimed to provide electricity to pumps at the time of blackout, using inert energy of free-wheeling turbines [2]. At 01:00 on April 25, the process began to reduce the reactor power from the nominal value (3.2 GW thermal). At 13:05, when the power decreased to 1.6 GWt, one of two turbines was isolated. Although it was planned to continue decreasing the reactor power, because of the order from the Kyiv grid center, the 4th block continued to operate at the power level of 50 %.

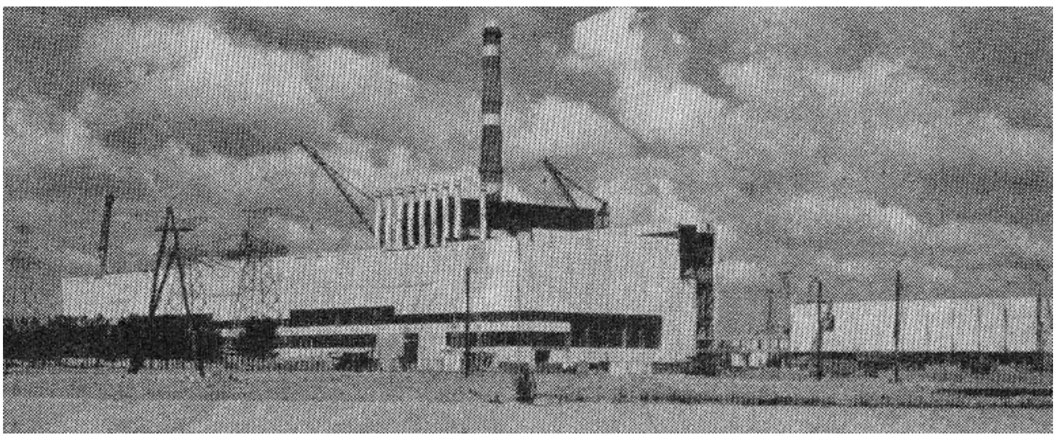

Fig. 1: Construction of No. 1 block at Chernobyl NPP.

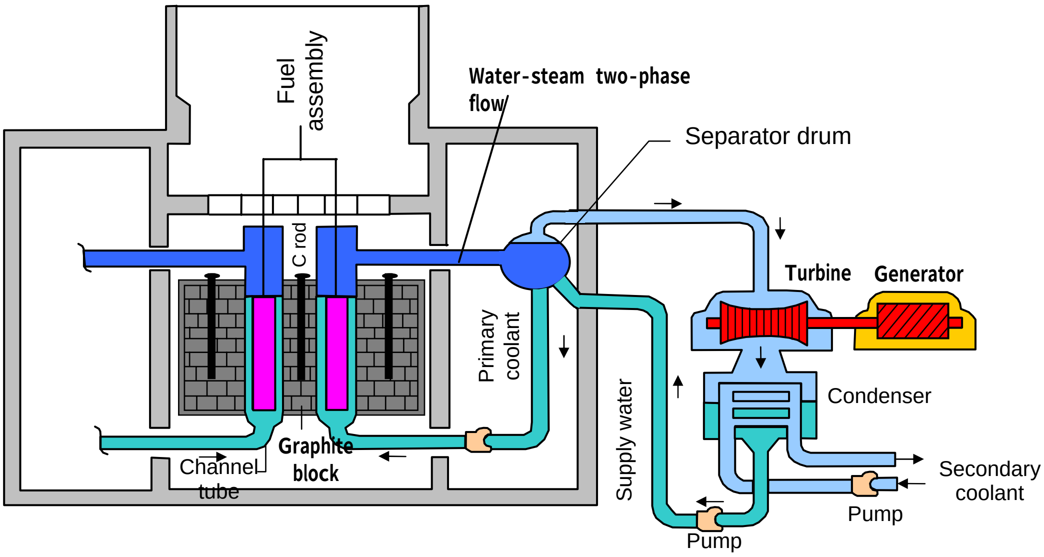

Fig. 2: Basic scheme of RBMK

Table 1: Basic parameters of RBMK1000

Item	Contents
Power	1 GW electricity, 3.2 GW thermal (Efficiency 31.3%)
Turbine	500 MW×2
Reactor core size	Cylinder diameter: 11.8 m, height: 7.0 m ・ Primary structure is a pile of graphite moderator block. ・ Each block has a vertical hole in its center to penetrate a channel tube.
Graphite block	A square box of 25cm×25cm×60cm. Density:1.65 g/cm^2. ・ Diameter of the hole for channel tube: 11.4cm ・ Total weight of graphite block: 1,700 ton
Reactor space size	Cylindrical diameter: 14.52 m, height 9.75m. ・ Graphite reflector blocks are surrounding the reactor core. The metal shroud confines the reactor space, making it airtight. ・ Design pressure of the core space: 0.8kg/cm^3. ・ Outside the shroud, annulus water tank of 2.4 m width, a layer of sand and then concrete shield. ・ The upper core plate (diameter: 17m, height: 3m) and the lower core plate (diameter: 14.5m, height: 2m) have holes like a honeycomb for channels to penetrate.
Fuel channel	Number of fuel channel: 1,661 ・ Outer diameter: 88 mm, inner diameter: 80 mm. ・ Tube material: zirconium ally for the position corresponding to reactor core, welded with stainless steal tubes at upper and lower sides. ・ A fuel assembly is inserted in each fuel channel. ・ Coolant water goes up inside the fuel channel, boiling to steam. ・ Refueling is performed while operating reactor, by isolating channel tube one by one from the coolant loop.
Control rod channel	211 channel ・ Neutron absorber: boron carbide ・ Automatic rod: 12, local automatic rod: 12, manual rod: 115, emergency rod: 24, local emergency rod: 24, shortened rod: 24.
Fuel	Uranium dioxide (UO2). Enrichment: 2 %. ・ Fuel pellet size: diameter 11.5 mm, height 15 mm. ・ Fuel rod: outer diameter 13.6 mm, length 3.5 m. Tube material: zirconium alloy, thickness 0.9 mm. ・ Amount of uranium in the core: 194 ton. Designed burnup: 20 MWD/kg
Fuel bundle	Bundle length 7 m. ・ Two sub-bundles (3.5 m) are connected up and down. ・ Sub-bundle: length 3.5 m, 18 fuel rods are fixed around the central supporting rod. ・ Uranium amount per fuel bundle: 114.7 kg
Coolant loop	Two loops. Coolant: light water ・Inlet temperature of fuel channel: 270°C. ・ Out let: 284°C, pressure 70kg/cm^2, steam quality 14.5 %. ・ 4 circulation pumps per loop (including one reserve). Totally 8 pumps. ・ Coolant flow rate: 37,600 ton/h. Steam supply: 5,800 ton/h.

The above information is mainly based on the 1986 USSR report [2].

At 23:10 on April 25, the shutdown procedure was restarted. Then 00:00 on April 26, the shift of the control room changed from Tregub's team to Akymov's team (each constitutes 4 staff). Soon after the shift change, when the power control system was replaced from local automatic control to automatic control, the reactor power suddenly fell down almost to zero. The generator test was planned to be performed at power level of 700 – 1,000 MW. If it could not be done, the next chance would be several years later.

✧ The 4th block exploded

Fourteen people were at the control room of the 4th block. Dyatlov, Deputy Chief Engineer was in responsibility to carry out the test. By the order of Dyatlov, the operators tried to revive the reactor power, by pulling out almost all control rods from the reactor core. As is shown in Table 2, around 01:00, the rector was somehow stabilized at the power level of 200 MWt. Then, it was decided to carry out the generator test at the power less than the planned.

At 01:23:04, by closing the steam valve to No.8 turbine, the generator test started using inert energy of the free-rotating turbine. According to Dyatlov's testimony, the reactor power was stable during the test and there was no sign requiring operator's attention or alarms.

The emergent event started just at 01:23:40 when the operator turned on the AZ-5 button to shut down the reactor by inserting all control rods into the core. On the contrary to the intension of the operator, a positive scram phenomenon happened, which led a power surge at the lower part of the core, damaging several nuclear fuels and channel tubes. Then, following the rupture of channel tubes, a large amount of vapor appeared at the core. A bigger-scale power surge was caused by the effect of positive void

Table 2: Event chronology (April 25 – 26, 1986)

01:00 April 25	Shutdown procedures began by reducing the power from the nominal value (3.2 GWt).
03:47	Power decreased to 1.6 MW.
04:13 -12:36	At power level of 1.6 GW, control systems and vibration characteristics were checked of No. 7 and No. 8 turbine-generators.
13:05	One (No. 7) of two turbines was detached.
14:00	ECCS system was detached. Owing to the request from the Kyiv electric center, the power was kept at 1.6 GWt.
23:10	Shutdown procedure restarted.
00:00 April 26	The control room shit was replaced from Tregub team to Akymov team.
00:28	At 500 MWt, power control system was switched from local automatic control to average automatic control. When switching, abrupt power decrease occurred to almost zero power.
00:41-01:16	No. 8 turbine was detached. Its vibration characteristics were measured during inert rotation.
About 01:00	After the efforts to increase the power, the reactor somehow became stable at 200 MW. The decision was made to perform the emergency generator test at the level below the planned power.
01:03 and 01:07	Two main circular pumps (MCP) were added in operation. All eight MCP began operating.
01:23	According to the analysis after the accident, at this time the reactor was under the extremely unstable condition because of the increase of positive void reactivity coefficient due to withdrawal of almost all control rods as well as reactor operation at the low power level. The operators, however, did not know such situation.
01:23:04	The test was started by closing the steam valve to No. 8 turbine. Coolant flow rate of 4 MCP that were connected to the test generator decreased to some extent, which in turn increased steam generation a little at the core. The effect of this increase was compensated by a small increase of the pressure as well as by gradual insertion of automatic control rods. The reactor power was kept stable during the test, without any extraordinary symptom prompting operator action or alarming signal.
01:23:40	Chief operator Akymov turned on the scram button (AZ-5).
01:23:43	Alarm of "rapid power increase" and "over power".
01:23:46-47	Loss of electricity for MCP. Flow rate decreased. High pressure and high water level in steam separator tank. "Control system failure" alarm.
01:23:49	"High pressure in the reactor space", "Loss of electricity for control rod", "Failure of driving automatic control rods" signals
01:24	The operator wrote in the log note, "01:24 strong explosion. Control rods stopped halfway before reaching the bottom of the core. Loss of driving electricity for control rods." According to eyewitnesses who were outside the reactor building, there were two sequential explosions, blowing up something like fireworks into the night sky.

・The above sequences are mainly cited from the Steinberg report [3].

coefficient of reactivity, which led to explode the reactor and destroyed the building. According to the analysis after the accident, the explosion occurred 6-7 seconds after pushing AZ-5. Eyewitnesses outside the reactor building told that there were a series of explosions like fireworks up into the night sky. Concerning the accident sequence, there are several versions. The above is based on the Steinberg report in 1991 that reinvestigated the cause of the accident by the request of the USSR parliament [3].

It was 3 am when the first information on the accident reached the responsible person of the Soviet Communist Party in Moscow. At 9 am in the morning, the first expert team flew from Moscow and arrived at the scene of the accident in the afternoon. A special medical team from Moscow also arrived in the evening. They have checked patients of workers and firefighters being cared at the Pripyat hospital because of acute radiation syndrome. They selected persons to be sent to Moscow for special treatment. Mr. Shcherbina, Deputy Ministry of USSR, nominated as the chairman of the governmental committee for the Chernobyl accident also arrive at Pripyat in the evening of April 26. The first tasks of the government committee meeting held in the night of April 26 were the followings:

- ✧ To determine the method how to extinguish the graphite fire that continued in the destroyed core, discharging a large amount of radioactivity into the environment,
- ✧ Decision whether or not residents in Pripyat should be evacuated.

The committee decided to extinguish the fire by dropping the material such as sand, lead, boron etc. onto the core using military helicopters. After the long discussion, by the decision of Shcherbina, the evacuation of Pripyat was scheduled on the next day.

✧ 120 thousand evacuees

The weather was fine in Pripyat on April 26. Most residents (population 50,000) did know that something serious event happened at the NPP. They spent, however, that day as usual Saturday. A lot of people were at shops and even a wedding was celebrated. Some people watched the smoking 4th block from the roof of the apartment while sunbathing (Fig. 3-4). Only few people were afraid of radiation and stayed inside their flats closing windows.

Fig. 3. The 4-th reactor on the day of the accident. Photo by Igor Kostine.

Fig. 4. View of Sarcophagus from the roof of an apartment in Pripyat. Photo by Imanaka, October 2005.

It was lucky for the people in Pripyat that the first “hot” radioactive plume released from the destroyed 4th block did not hit directly on the city. It flowed to the west from the destroyed reactor, where pine trees within 5 km died in several days because of strong radiation (Fig 5).

On April 27, because of the change of wind direction, radiation dose rate in Pripyat began to increase. At 07:00, dose rate of 2 - 6 mSv/h was recorded inside Pripyat. Around noon, the following was announced through the local radio: “Dear citizens! Evacuation was ordered in relation with the accident at NPP. Please take passport, indispensable materials and food for three days. Evacuation will begin at 14:00”. 1,200 buses were mobilized from Kyiv to evacuate Pripyat. 45,000 people were evacuated in two hours. Panic that the authority was afraid of did not happen. Many evacuees thought that they could come back home in three days, but they could not restore their life in Pripyat again.

The region surrounding Chernobyl NPP was traditional rural area except Pripyat city. Although Pripyat city were evacuated quickly on the second day, the people within the 30 km zone were left uninformed for a while. It was on May 2, one week after the accident that the evacuation was decided of the people who were living in the 30 km zone other than Pripyat. Their evacuation began on May 3. In a week about 71,000 people left their home. Compared with the case of Pripyat, the evacuation of rural towns/villages was far more difficult. Several hundred thousands of livestock were evacuated together with their owners. Many people reminded their experience at the time of the Nazi invasion. But, different from the previous experience, they could not return home this time. In total 116,000 people were evacuated from the 30 km zone around the Chernobyl NPP in two weeks after the accident.

Figure 6 indicates radiation monitoring data in settlements within the 30-km zone on May 1, 1986 [4]. The maximum of 3,306 μGy/h is seen in Krasnoe village about 6 km north from the ChNPP. The main contamination in this direction was considered to occur on April 27-28 and Krasnoe village was evacuated on May 3. This situation makes us easily suppose serious radiation exposure of residents staying there. Imanaka previously estimated that some fraction of the residents in Krasnoe could receive more than 1 Gy of external dose, a criterion of acute radiation syndrome [5].

Meanwhile, according to the Chernobyl Forum report [6] that was released at a conference held by IAEA and other organizations in September 2005 as a summary of 20-year investigation on the consequences of the accident, the average dose of evacuees was evaluated to be about 30 mSv and their maximum was several hundreds of mSv.

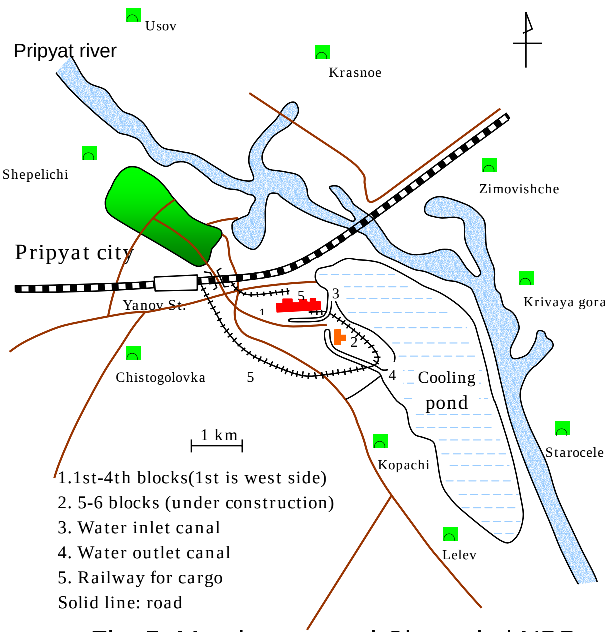

Fig. 5: Map just around Chernobyl NPP.

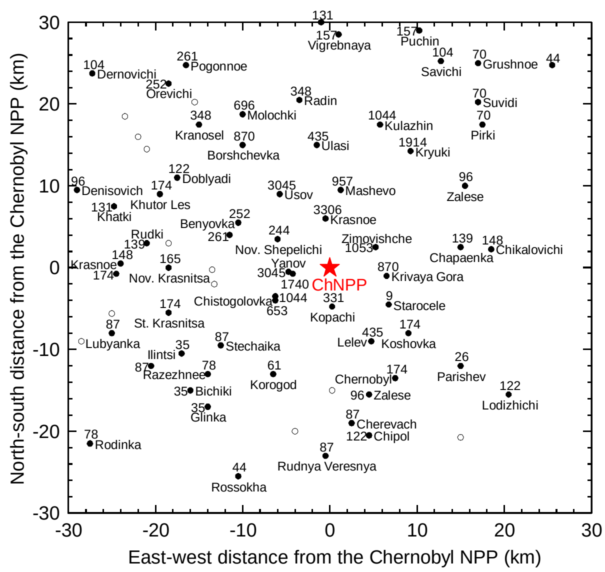

Fig 6. Dose rate in air at settlements within the 30-km zone around Chernobyl NPP on May 1, 1986 [4], unit: μGy/h.

✧ Accident liquidation and construction of Sarcophagus

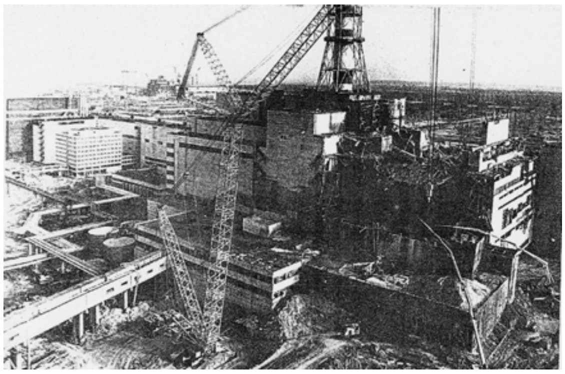

Fig. 7: Construction of Sarcophagus

Five minutes after the explosion at the 4th block, the first firefighter team arrived at the scene. It was firemen of the power station led by lieutenant Pravik. Five minutes later another firemen team led by lieutenant Kybenok arrived from Pripyat city. Pravik's team started extinguishing the fire on the roof of the turbine building in order to prevent the spread of the fire. The Kybenok's team fought the fire at the central hall of the destroyed 4th reactor. Nobody hesitated at the fight being afraid of radiation. Rather, they were not taught about danger of radiation. They became feel sick one after another, and were carried to the hospital in Pripyat.

When the explosion happened, operators at the control room of the 4th block could not understand what happened at the reactor. As shown in Table 2, operator wrote in a log note, "At 1:24, a strong explosion, control rods stopped halfway before reaching the bottom of the core". The first priority for operators was to prevent the reactor from destruction. Therefore, they tried to insert control rods to the full position and keep the core cooling by continuing pumping the coolant. In reality, however, the reactor core was completely destroyed by the first explosions. The operators and other workers should quickly evacuate and go to the shelter. On the contrary, as a result of useless efforts and unreasonable orders to tackle the situation, radiation symptom also appeared in operators.

According to the reports from the USSR authorities, about 300 people was hospitalized, 28 out of which died because of acute radiation syndrome. In addition, one worker became missing under the debris, another died of severe burn on the day of the accident. Adding one more death of other reason, it was reported that 31 people died in total by the Chernobyl accident.

The chemical detachment of the USSR army that was being trained to prepare nuclear wars arrived at the scene on the second day, April 27. It is certain that the first step to liquidate the accident consequences was carried out by this regular army. But, details of their works and radiation dose were yet unknown. During three weeks of their stay, debris such as fuel rods, graphite block etc. thrown from the core and scattered on the ground around the 4th block building were cleared in order to begin the construction of "Sarcophagus" (Fig. 7).

In June, the construction began of "Sarcophagus" that would confine the whole destroyed block by the concrete structure. "Patriotic workers" gathered to Chernobyl from all over USSR. They did heroic works under the condition of strong radiation.

Fig. 8: Working scene of liquidators. From DVD movie "Sacrifice" [7].

A large scale mobilization of reserves was also taken place for the works of decontamination of the territory within the Chernobyl station as well as settlements within the 30 km zone. Their age was 30 – 40 years old and called “liquidators”. The right photo in Fig. 8 shows a scene of clean-up work of radioactive debris that had scattered on the roof of 3rd block. It was done by human-wave tactics at the final stage of the Sarcophagus construction in September 1986. About 3,000 reserves were engaged in this work. The exposure limit was set 25 Roentgen (about 250 mSv), but it is said there were a lot of cases of over exposure.

Up to the end of 1990, the total number of liquidators amounted to 800,000 people, among which 200,000 worked in 1986 and 1987 under the condition of strong radiation.

✧ 28 acute radiation deaths

In the evening of the day of the accident, a special medical team arrived from Moscow. Among the patients accommodated at the hospital in Pripyat, serious ones were selected to be sent to No. 6 hospital in Moscow. Dr. Gale, a US specialist of bone marrow transplantation came to Moscow to help the treatment. He and his colleague did operation of bone marrow transplantation for 13 patients, but all cases could not survive. In spite of insensitive care at No. 6 hospital, 28 people died of radiation syndrome. Tabl 3 lists these 28 people together with two persons who died on the day of the accident. It is noted that most of the

Table 3. List of deaths by radiation syndrome

Name	Working place	Age	Date of death	Remarks
Firefighters 6: persons				
Lieutenant Pravik V.P.	NPP fire station	23	May 11	
Lieutenant Kybenok V.M.	Pripyat fire station	23	May 11	
Sergeant Vashchuk M.V.	do.	27	May 14	
Staff sergeant Ihnatenko V.I.	do.	25	May 13	
Staff sergeant Tytenok M.I.	do.	26	May 16	
Sergeant Tyshchura V.I.	do.	26	May 10	
Plant staff and business traveler: 24 persons				
Akymov O.F.	Chief operator shift	33	May 11	15Gy
Toptunov L.F.	Reactor operator	25	May 14	
Kudryavtsev O.H.	Trainee operator	28	May 14	
Proskuryakov V.V/	do.	31	May 17	
Perevozchenko V.I.	Chief reactor engineer	39	June 13	
Kurhuz A.K.	Reactor engineer	28	May 12	
Khodemchuk V.I.	Machine engineer	35	April 26	Missing inside debris
Dehtyarenko V.M.	do.	31	May 19	
Perchuk K.H.	Turbine engineer	33	May 20	> 10 Gy
Vershynun Y.A.	do.	27	July 21	do.
Brazhnyk V.S.	do.	29	May 14	do.
Novyk O.V.	do.	24	July 26	do.
Lelechenko O.H.	Deputy of electric section	47	May 7	25 Gy, dead in Kyiv
Baranov A.I.	Electric engineer	32	May 20	
Lopachuk V.I.	do.	25	May 17	
Shapovalov A.I.	do.	45	May 19	
Konoval Y.I.	do.	44	May 28	
Sytnykov V.I.	1・2 block deputy engineer	46	May 30	
Orlov I.L.	Deputy chief of 1st block	41	May 13	
Popov H.I.	Engineer	46	June 13	Trip from Harkov
Savenkov V.I.	do.	28	May 21	
Shashenok V.M.	Engineer of industrial meter	45	April 26	Dead by burns on the day
Luzhhanova K.I.	Guard	59	July 31	Entrance gate
Iwanenko K.O.	do.	53	May 26	Spent fuel building

deaths occurred in the middle of May, 2 - 3 weeks after the accident, which indicates that the blood-forming functions of their bone marrow were destroyed by radiation.

According to Gorbachev's speech on May 14, about 300 firemen and plat staff were hospitalized because of radiation syndrome. In November 1986, this number was reduced to 237 people. Then, after "reexamination of syndrome", the current number is given to be 134 cases [8].

When the present author visited the Chernobyl museum in Kyiv, he found an exhibition of a medical certificate that a serviceman (31 yr) of Ukrainian ministry of Internal Affairs was admitted at No.25 hospital in Kyiv on May 22 – August 12, 1986 and received bone marrow transplantation. He was again at hospital December 1 – 31, 1986. His dose was estimated 3.2 – 3.7 Gy. Of course this case was not included in the official reports. We have to wonder how many such patients were who were not included in official reports.

✧ Acute radiation syndrome among residents

According to official reports beginning from the USSR report [2] in 1986 up to the Chernobyl Forum report [6] in 2005, acute radiation syndrome occurred only among station staff and firefighters who were at the scene of the accident, but no radiation syndrome was observed among residents living around the ChNPP. However, a number of descriptions about radiation syndrome among the residents were found in the secret protocols of the communist party that was disclosed after the collapse of USSR [9]. In the former USSR, The communist party was the core of its centralized power system, and its central committee in Moscow was the summit of the power. When the Chernobyl accident occurred, a special

Table 4. Excerpts of descriptions of the health state of inhabitants from the secret protocols of the Communist Party of the Soviet Union .

<Date of protocol>	<Description of the health state of people>
1986 May 4:	As of May 4, 1,882 people are hospitalized in total. Total number of examined people reached 38,000. Radiation disease of various degrees of seriousness appeared in 204 people, including 64 infants.
May 5:	Total number of hospitalized people reached 2,757, including 569 children. Among them, 914 people have symptoms of radiation disease. 18 people are in a very serious state and 32 people are in a serious state.
May 6:	As at 9:00 on May 6, the total number of hospitalized people reached 3,454. Among them, 2,609 people are in hospital for treatment, including 471 infants. According to confirmed data, the number of radiation disease cases is 367, including 19 children. Among them, 34 people are in a serious state. In the 6th Hospital in Moscow, 179 people are in hospital, including two infants.
May 7:	During the last day, an additional 1,821 people were hospitalized. At 10:00 May 7, the number of people in hospital for treatment is 4,301, including 1,351 infants. Among them, diagnosis of radiation disease was established in 520 people, including staff of the Ministry of Internal Affairs of the USSR. 34 people are in a serious state.
May 8:	During the last day, the number of hospitalized people increased by 2,245, including 730 children. 1,131 people left hospital. As at 10:00 May 8, a total of 5,415 people are in hospital for treatment, including 1,928 children. Diagnosis of radiation disease was confirmed for 315 people.
May 10:	During the last two days, 4,019 people were hospitalized, including 2,630 children. 739 people left hospital. In total 8,695 people are in hospital, including 238 cases with diagnosis of radiation disease, among which 26 are children.
May 11:	During the last day, 495 people were hospitalized and 1,017 people left hospital. In total, 8,137 people are in hospital for treatment and examination, among which 264 people with diagnosis of radiation disease. 37 people are in serious state. During the last day 2 people died. Total number of death by the accident amounted to 7 people.
May 12:	During the last day, 2,703 people were hospitalized, most of which were in Belarus. 678 people left hospital. 10,198 people are in hospital for treatment and examination, among which 345 people have symptom of radiation disease, including 35 children. Since the time of the accident, 2 people perished and 6 people died of diseases. 35 people in serious state.

remark: The total number of 40 protocols are contained in the secret document.

working group was formed at the central committee to decide basic policies to cope with the accident consequences. The disclosed documents were protocols of the WG meetings.

Excerpts from the protocols are shown in Table 4. The numbers of deaths and serious patients seem to correspond to those of station staff and firefighters, but it is certain that a lot of radiation patients were also among residents. For example, on May 12 when the evacuation of the 30-km zone almost finished, it was written, "10,198 people are in hospital for treatment and examination, among which 345 people have symptom of radiation disease, including 35 children".

A noteworthy description is that two infants were at No. 6 hospital on May 6. In the protocol of the same day, it was written "taking into consideration the situation that American doctors are working at No. 6 hospital, the proposal from Health Ministry was agreed that the number of patients and their condition should be announced properly". This means that the information would not have been released if Dr. Gale and his colleague were not at the hospital.

Meanwhile, Lupandin of Sociological Institute, Russia investigated in 1992 the remaining carte that was made at the time of the accident at the central district hospital, Khoyniki, Gomel region, Belarus. A part of Khoiniki district was included in the 30 km zone (Fig. 9). Lupandin found 8 cases of radiation diseases as well as 20 cases with some radiation symptoms. He described that more than 1,000 cases of acute radiation diseases could have been in total at that period [10].

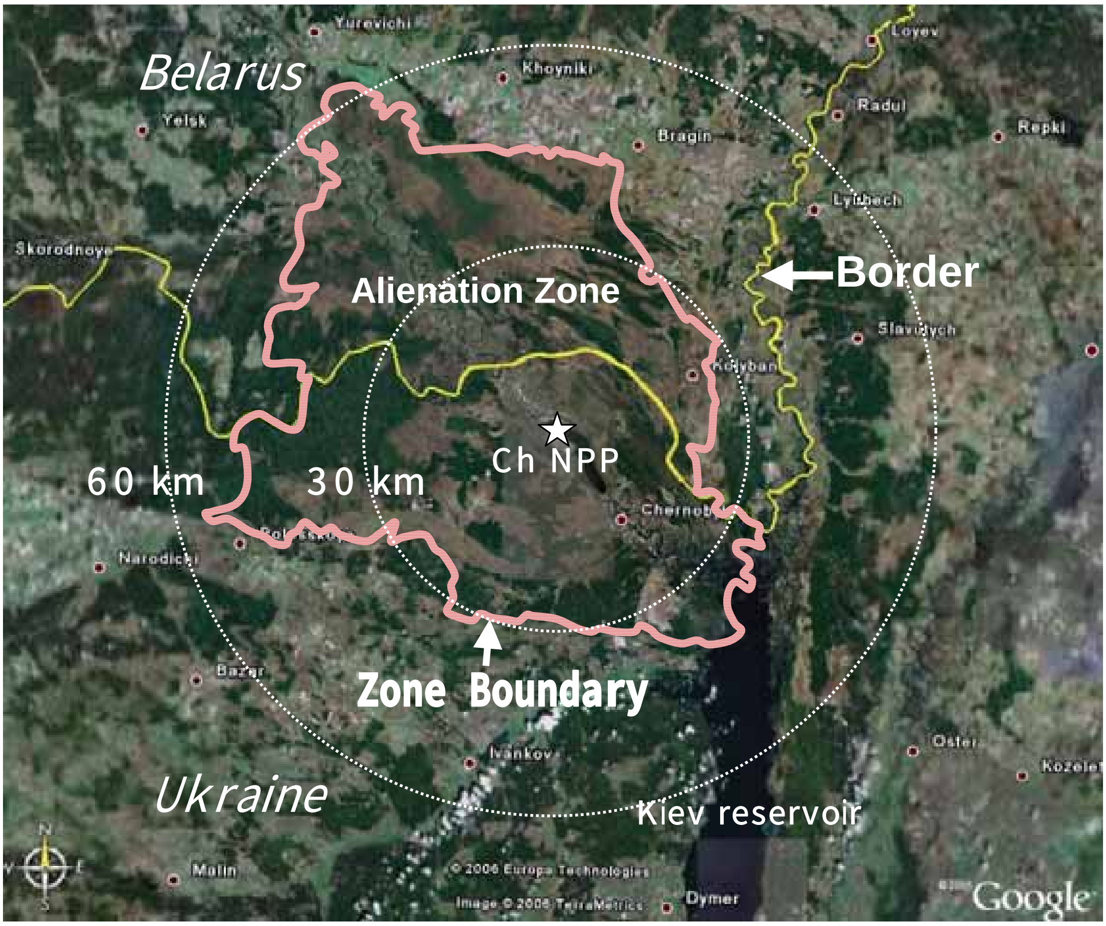

Fig. 9. Current alienation zone around Chernobyl. The areas on Ukrainian and Belarusian sides are 2,000 and 1,700 km^2, respectively. The map is made based on the figure in *National Geographic,* April 2006. Basic photo is made using Google Earth.

✧ The blame was put on the operators

In August 1986 USSR government presented the report on the Chernobyl accident to IAEA [2]. Then the first expert meeting on the Chernobyl accident was held in August 25 – 29, 1986 at the IAEA headquarters in Vienna. Specialists from the western countries were impressed with the frank presentation by Dr. Legasov of the chief of the Soviet delegation, and accepted his explanation about the accident.

According to the 1986 USSR report, the reason for the Chernobyl accident was "a very rare combination of a series of regulation violation by the operators". Six violations pointed in the USSR report are listed in Table 5. As a result of the combination of these violations, the reactor began runaway during the test of emergency generator. The operator, having noticed sudden power increase, turned on the scram button, AZ-5, but it was too late to stop the reactor.

Table 5. Six violations by the operators pointed in the 1986 USSR report.

1. Reactor was operated in a condition that operational reactivity margin (ORM) was below the permissible limit.
2. The generator test was conducted below the planned power level in the test program.
3. Coolant flow rate exceeded the limit because two additional pumps were operated.
4. Reactor trip signal for steam valve closure was bypassed.
5. Reactor trip signal for parameters in steam separator tank was bypassed.
6. ECCS signal was dispatched.

Dyatlov, Deputy Chief Engineer was responsible at the control room at the time of the accident. He was sentenced to 10 years confinement in 1987. After being discharged from the prison earlier than the term in 1990, he wrote an article [11] appealing, "There was noting extraordinary in the control room until the operator switched on AZ-5. It was three seconds after pushing AZ-5 when the alarms of power increase appeared. Operators should not be blamed due to decrease of operational reactivity margin (ORM) because there was no instrument directly indicating ORM. Operating reactor at low power was not forbidden, but such regulation was made after the accident... The primary causes of the accident was design defects of the reactor as well as the people who did not take countermeasures knowing such design defects" and "The 1986 USSR report was full of lies. I can not understand why specialists of IAEA could accept such explanation".

It was already pointed out in May 1986 that the main causes of the Chernobyl accident likely were

Fig. 10 Control room of 4th block. October 2002.

Fig. 11 Control rod position panel of 1st block

"positive void coefficient of reactivity" and "positive scram" [3]. It is a conventional trick by the authorities to put the responsibility on personnel at the scene. If the cause of the accident was found to be the design defects in RBMK, the responsibility should be asked of its designer of Academician Alexsandrov, the president of USSR Academy of Sciences. In addition, it would become difficult to continue operation of 14 RBMK reactors other than the ChNPP. At the beginning of July, the official conclusion on the cause of the accident was decided at the meeting of the central committee of the USSR communist party where Gorbachev also participated [12].

With the progress of "Perestoroika" and "Glasnost" at the final period of USSR, intensive efforts were made at the USSR parliament to reevaluate the consequences of the Chernobyl accident. In 1991 a special committee nominated by the parliament released a report. It concluded that the real cause of the accident was not the regulation violations by operators, but design defects and idleness of authorities neglecting them. According to the report, the accident such as Chernobyl was inevitable [3].

✧ Positive void reactivity coefficient and positive scram

Neutrons produced by nuclear fission are with high energy (average 2 MeV), the speed of which is about 1/10 of light. Because of a small probability of high speed neurons to be caught by other uranium nuclei, it is difficult to maintain fission chain reaction using high energy neutrons. So, in thermal reactors such as RBMK, neutrons are designed to collide with light nuclei of "moderator" to slow down the speed. If the distribution of neutron speed becomes equilibrium with the temperature inside the reactor, these neutrons are called as "thermal neutrons". The ability of thermal neutrons to cause fission reaction with uranium nucleus is about 500 times larger than "fast neutrons". Thermal neutrons are also captured easily by other nuclei than uranium. Therefore, thermal reactors are designed to slow down neutrons using moderator and, avoiding neutron capture by materials other than fuel, make thermal neutrons to be captured by uranium as much as possible. Good candidates of moderator are heavy water and graphite, while light water is worse than them because light water itself will capture neutrons.

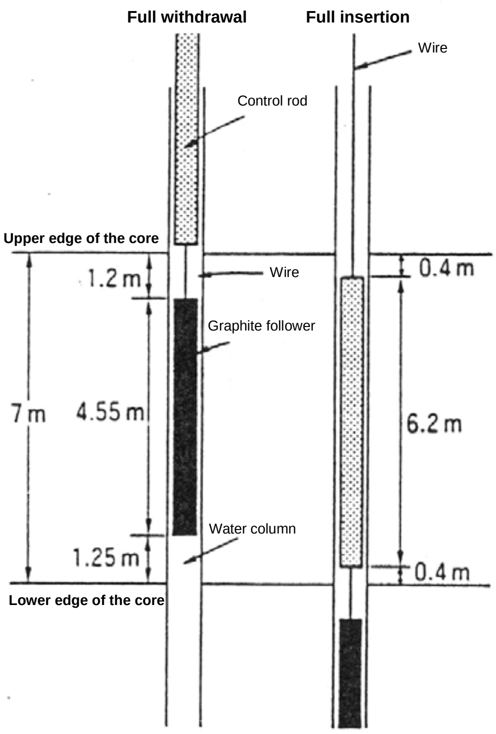

Fig. 12. Control rod and graphite follower

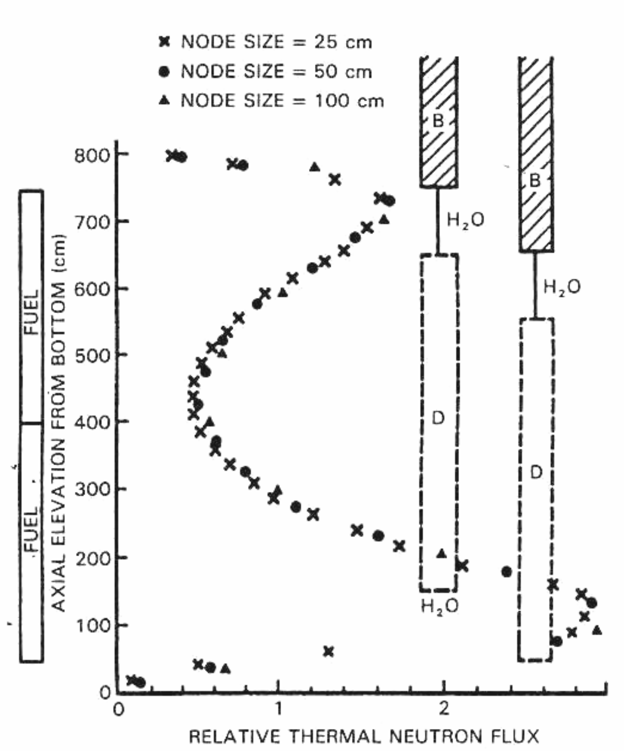

Fig. 13: Power distribution before the

¤Positive void coefficient of reactivity: “Reactivity” indicates a scale how fission rate is increasing or decreasing. If reactivity = 0, the number of fission per unit time is constant. If it >0, the reactor power will increase and if it<0, the reactor power will decrease. Reactivity depends on various factors such as position of control rods, fuel enrichment, fuel temperature etc. “Void coefficient of reactivity” indicates how reactivity will be effected by density change of coolant material. If it is positive, the reactor power will increase when steam fraction at the core increases.

In the case of the Chernobyl accident, a positive value of void reactivity coefficient was exaggerated by the facts operating the reactor at low power and pulling almost control rods out of the core. After several channel tubes were ruptured by “the first power excursion”, which made the steam fraction having increased. Subsequently a more large power excursion was caused by the positive void coefficient of reactivity”. It lifted up the upper structural plate tearing all channel tubes at a time, which led to another excursion [1,3].

¤Positive scram: “Scram” means emergency shutdown of nuclear reactor. “Positive scram” is a word made after the Chernobyl accident, reflecting an unbelievable event that the reactor power increased by pushing the scram button.

The structure of RBMK control rod is shown in Fig. 12. A graphite follower is pending under the control rod that absorbs neutrons. The left part of the figure illustrates the complete pullout, making a water column under the graphite follower at the bottom of the core. The right part shows the full insertion. Plotted data in Fig. 13 are power distribution it the core just before the accident [13]. An interesting feature is seen that a large peak of power distribution was at the lower part of the core. The operator of the 4th block pushed the scram button (AZ-5) when almost control rods were fully pulled out. Water columns in the left part of Fig. 12 were replaced with graphite followers, producing positive reactivity at the lower part of the core, which was considered to cause the first power excursion [1].

✧ The amount of released radioactivity

Amount of radioactivity accumulated in the reactor core of 1 GWe NPP is about 1.5×10^{20} Bq, excluding those of short half-lives. It is rather difficult task to estimate the amount of radioactivity released into the environment for such case as Chernobyl because radiation monitor was useless in the situation that the reactor core exploded and ruined together with the building. Several methods were elaborated to estimate the amount of released radioactivity, for example, using ground contamination data of all over the world from Chernobyl fallout. Table 6 is the radioactivity release estimated in the Chernobyl Forum report in 2005 [6]. Rare gas elements such as ^{133}Xe were released 100 % of the reactor core. Radioiodines to which attention should be paid at the early stage were released 55 %. ^{137}Cs, which is important at long-tem contamination, was 30 %. Smaller fractions were seen for less volatile isotopes of ^{90}Sr and ^{239}Pu. Compared with previous values given in the 1986 USSR report, these estimates were 2.8 and 2.3 times

Table 6. Estimates of radioactivity released by the Chernobyl accident
(decay-corrected to 1986.4.26)

Nuclide	Half life	Released activity, Bq	Ratio to core inventory
Xenon-133	5.3 days	7×10^{18}	100 %
Iodine-131	8.0 days	2×10^{18}	55 %
Caesium-137	30 years	9×10^{16}	30 %
Strontium-90	29 years	1×10^{16}	4.9 %
Plutonium-239	24,000 years	2×10^{13}	1.5 %
＜Total release including others＞		1.4×10^{19}	About 10 %

large for ^{131}I and ^{137}Cs, respectively. In total, about 10 % of the radioactivity in the core was released into the environment beyond the territory of ChNPP.

¤Where is nuclear fuel?: The nuclear fuel mass loaded in the core of the 4th block was 190 ton. According to the 1986 USSR report, about 3 % of nuclear fuel was released, while the rest remained in the core where channel tubes, fuel tubes, graphite blocks etc were crowded together with materials of sands, lead etc thrown down from helicopters to distinguish the fire (about 5,000 ton). Two year after the accident, TV camera was inserted into the core through a hole bored in the side wall of the reactor cavity. Surprisingly almost vacant space was found at the position of the reactor core (Fig. 14) [14]. 5,000 ton of material did not reach the core, but only piled up on the floor of the central hall.

Part of the reactor core was blown up and away by the explosion around the destroyed building. The remaining fuel and channel tubes melted due to high temperature and formed materials like lava, which moved along the floor and corridor to the lower compartments and dropped into pools (Fig.14). Most of 1,700 ton graphite in the core was considered to burn out during the fire that continued about 10 days. Interestingly, as can be seen in Fig. 14, a concrete panel of the building wall was on the bottom of the reactor cavity. Considering the size of the concrete panel, it was supposed that this panel fell down into the cavity while the upper core structure plate (2,000 ton) was blown up in the air by the explosion.

Strong radiation as well as additional layers of concrete pored during the construction of Sarcophagus is still preventing detailed investigation inside Sarcophagus. A current estimate for the amount of nuclear fuel remaining inside Sarcophagus is about 60 % (± 20 %) of uranium in the core at the time of the accident.

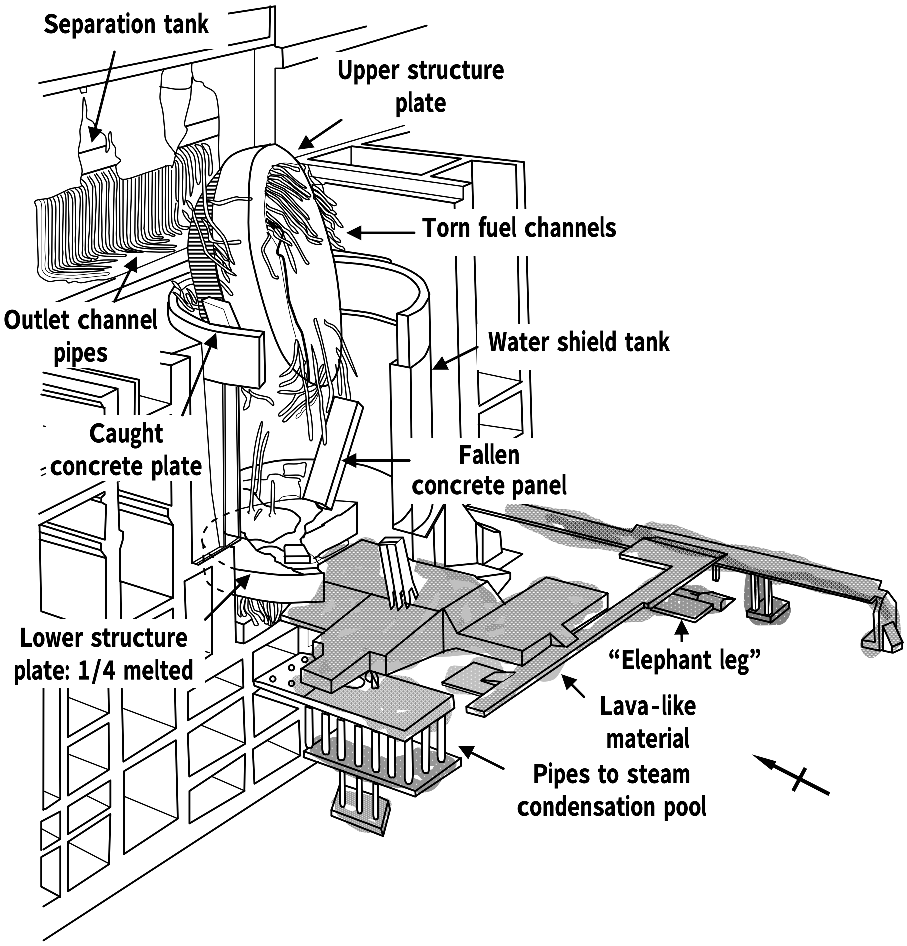

Fig. 14. Cross sectional view of the destroyed reactor.

✧ High level contamination at 200 km away was disclosed 3 years later

The Chernobyl accident happened in the midst of the cold war between USA and USSR. In USSR Mr. Gorbachev appeared in March of the previous year as the General Secretary of Communist Party, and began to propose two slogans of Perestoroika (reconstruction) and Glasnost (openness), but innate characteristics of the communist acquired for the past 70 years hardly changed. Citizens, even scientists, were forbidden to talk freely about the consequences the Chernobyl accident.

It was in spring of 1989, about three years after the accident that the situation seemed to changed with enlargement of the movement seeking for democracy in USSR. A ^{137}Cs contamination map around Chernobyl was published in a newspaper in Belarus for the first time. Although previous contamination maps reported by USSR specialists were limited to the area just near Chernobyl, the new map indicated a shockingly wide-scale of contamination. As can be seen in Fig. 15, there were spreading of strong contamination detachedly at distances 200 – 500 km from Chernobyl [15].

Various kinds of radionuclides will be released by reactor accidents. Iodine-131 (half life: 8 days) is important at the early stage after the accident, which irradiates specifically thyroid grand when incorporated into the body. From the point of long-term contamination, ^{137}Cs is the most important because of its long half life (30 yr), high volatility and transportability, and accessibility to foodstuff. A vast area was contaminated by ^{137}Cs in Ukraine, Belarus and Russia. (Table 7) [16].

In July 1989 the Belarus parliament, which began to criticize the Moscow government requesting countermeasures for the Chernobyl consequences, decided to relocate 110,000 residents from the contaminated territories. At the end of 1991, however, the central USSR government that should take primary responsibility of the Chernobyl accident disappeared. Then, the responsibility of countermeasures and compensation was transferred on the shoulder of newly independent governments. Each affected republic independently established laws for countermeasures and compensation from the damages by the Chernobyl accident.

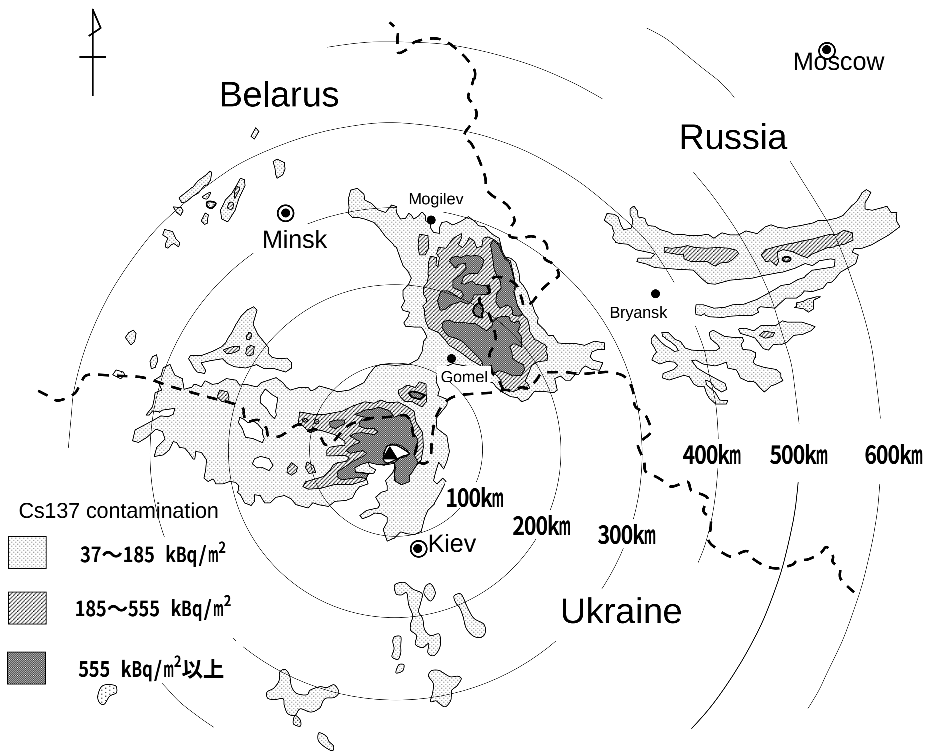

Fig. 15. Cesium-137 contamination map around Chernobyl.

Table 7. Areas contaminated with ^{137}Cs in three affected countries, km^2.

	Level of ^{137}Cs density (kBq/m^2)				
	37 ~ 175	175 ~ 555	555 ~ 1,440	> 1,440	>37 total
Russia	48,800	5,720	2,100	300	56,920
Belarus	29,900	10,200	4,200	2,200	46,500
Ukraine	37,200	3,200	900	600	41,900
Total	115,900	19,120	7,200	3,100	145,320

According to Chernobyl laws in these countries, contaminated territories are classified by the level of caesium-137 contamination on the ground as follows:

- > 1,440 kBq/m^2 :zone of alienation,
- 555～1,440 kBq/m^2 :zone of obligatory resettlement,
- 175～555 kBq/m^2 :zone of guaranteed voluntary resettlement,
- 37～175 kBq/m^2 :zone for radiation control.

✧ Almost all northern hemisphere was contaminated

In the morning of April 28, 1986, an alarm of radiation monitor sounded at the Forsmark NPP located in the southern part of Sweden, 1,200 km away from Chernobyl. Radioactivity leakage from the Forsmark plant was suspected, but no extraordinary was founded. In this morning radiation level also increased at other nuclear facilities in Sweden. Radioactivity likely came from the USSR territory passing over the Baltic Sea. It was 9:00 pm on April 28, responding the query from the Swedish government, that TASS News Agency in Moscow reported a short announcement about the accident at the Chernobyl NPP.

Table 8. Area of ^{137}Cs contamination in European countries (excluding Ukraine, Belarus and Russia): km^2

Country	Area (km^2)	Level of ^{137}Cs contamination, kBq/m^2		
		10～20	20～37	37～185
Sweden	450,000	31,000	33,000	23,000
Finland	337,000	32,000	59,000	19,000
Bulgaria	111,000	27,500	40,400	4,800
Austria	84,000	28,000	25,000	11,000
Norway	324,000	44,000	23,000	7,200
Rumania	238,000	54,000	13,000	1,200
Germany	366,000	29,000	14,000	320
Greece	132,000	21,000	8,300	1,200
Slovenia	20,000	8,100	8,700	610
Italy	301,000	15,000	7,000	1,400
Moldova	34,000	19,000	1,900	—
Switzerland	41,000	6,400	2,300	730
Poland	313,000	10,000	3,500	520
Hungary	93,000	5,200	230	—
U.K.	240,000	15,000	1,700	160
Estonia	45,000	1,700	280	—
Litania	65,000	50	—	—
Chex	79,000	13,000	3,500	210
Slovakia	20,000	6,800	800	20
Croatia	56,000	1,100	30	20
France	550,000	1,200	—	—

Remark: The level due to previous nuclear tests is 2 – 3 kBq/m^2.

The fire at the Chernobyl 4th block continued about 10 days, releasing a large amount of radioactivity. The first radioactive plume from ChNPP moved to the north-west direction, passing over the territories of Belarus, Latonia and the Baltic Sea, and then arrived at Scandinavia. The second plume went to the west direction over Belarus and Poland, which then reached Austria and Switzerland at the end of April. Table 8 shows ^{137}Cs contamination in European countries [17]. High level of the contamination was observed in the Scandinavian countries and the Alpine countries, where rain occurred with the passage of the radioactive plumes. Simply saying, the average level of ^{137}Cs contamination in European countries was equal to the sum of the past fallout contamination by all atmospheric nuclear tests in 50s and 60s.

✧ Radioactive fallout in Japan

The present author clearly remembers that it was in the morning of April 29,1986, the holiday for the previous Emperor's birthday that for the first time he heard the unfamiliar name of "Chernobyl". TV news told that something serious NPP accident occurred at "Chernobyl", while the details were unclear. The Chernobyl news became bigger and bigger with time, reporting radioactive contamination in various European countries. Japanese meteorologists told in TV rather negative opinions about whether or not radioactivity would come to Japan, traveling 8,000 km of the distance from Chernobyl.

Hearing the news of radioactive contamination in European countries, Imanaka and his colleague, which were used to radioactivity monitoring around nuclear facilities in Japan, half in doubt prepared to observe radioactive fallout from Chernobyl at their institute in Osaka. The first radioactivity was observed in rainwater that was sampled in the evening of May 3. A clear gamma-ray peak of 361-keV specific to ^{131}I was seen by gamma-ray spectrometry using Ge detector. Figure 16 indicates gamma-ray spectrum of air filter sampled on May 5. A series of fission products can be seen: ^{131}I, ^{132}I, ^{132}Te, ^{134}Cs, ^{136}Cs, ^{137}Cs, ^{103}Ru… Seeing this spectrum, Imanaka was surprised, asking himself, "Can we breathe this air?" He quickly calculated concentrations and, comparing them with permissible levels, said to himself, "It's irritating, but we can not live without breathing air". Iodine-131 concentration at that time was 0.8 Bq/m^3 [18]. If an infant breathed this air for one day, thyroid dose from inhaled ^{131}I would be 0.01 mSv using a

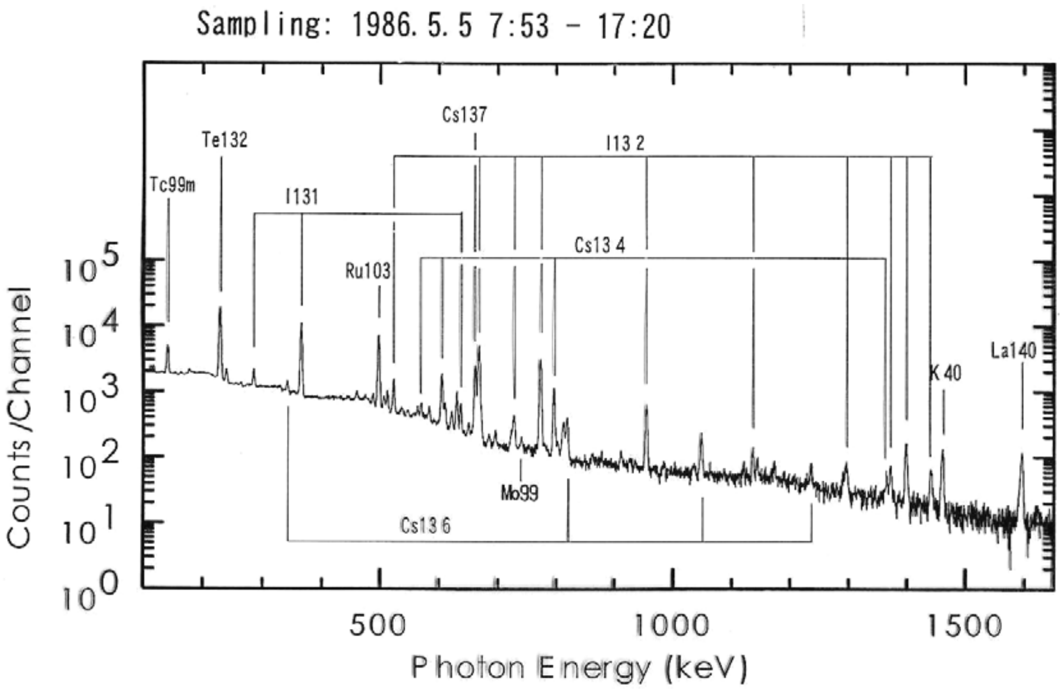

Fig. 16. Gamma-ray spectrum of air filter sampled May 5, 1986 at Research Reactor Institute, Kyoto University in Kumatori, Osaka.

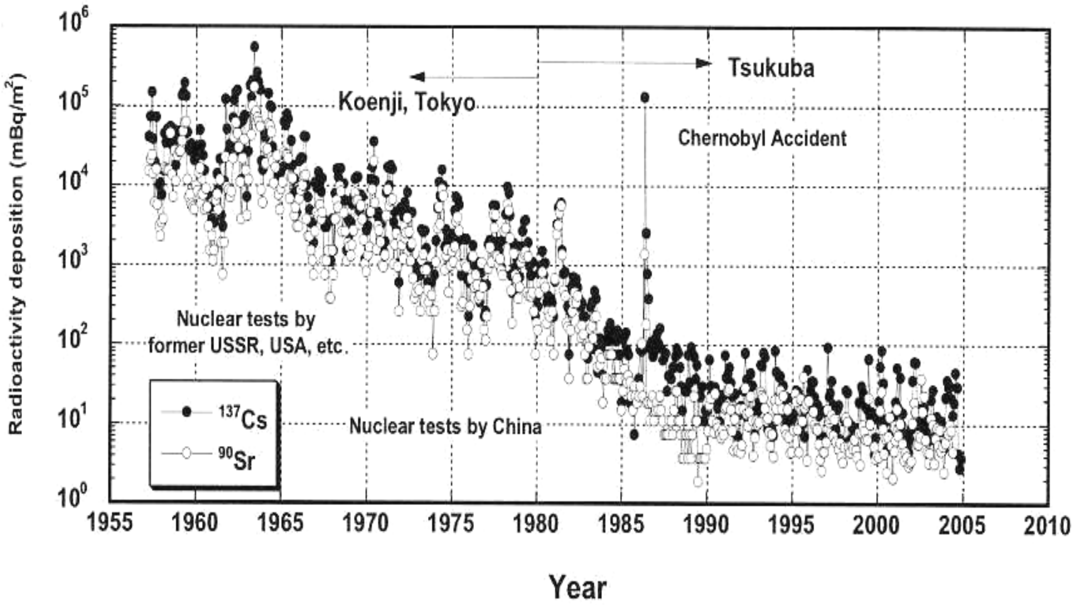

Fig. 17. Monthly deposition of ^{137}Cs and ^{90}Sr observed at Meteorological Research Institute, 1955 - 2005.

breathing rate of 3 m^3/day and a dose conversion coefficient of 3.7×10^{-3} mSv/Bq. This value seemed not so high to be nervous and not so low to be negligible.

The same level of fallout contamination was observed through the whole territory of Japan. The maximum ^{131}I concentration was 500 Bq/l in rainwater and 25 Bq/l in cow milk. The average deposited amount of ^{137}Cs was 200 Bq/m^2. Figure 17 is the deposition trend of ^{137}Cs and ^{90}Sr observed at the meteorological research institute for the past 50 years in Japan [19]. The ^{137}Cs deposition from Chernobyl was about 3 % of the total deposition from nuclear tests. Estimates of the average dose for the first year after the accident in Japan is shown in Table 9 [20]. Compared with annual natural background dose of 1 mSv, the whole body dose from Chernobyl could be negligible, but some attention should be put on thyroid doses.

Table 9. Average radiation dose in Japan by Chernobyl fallout during the first year after the accident. mSv

	Adults	Children
External exposure: whole body	0.003	0.003
Internal exposure: whole body	0.001	0.006
Internal exposure: thyroid	0.15	0.5

✧ Chernobyl sufferers

Almost all people who were on the northern hemisphere at the time of the accident received some radiation from Chernobyl. Of course the contamination around Chernobyl was predominant. Chernobyl sufferers can be classified as listed in Table 10. Other than the total body dose, evacuees and inhabitants received 10 – 100 times lager dose to thyroid from incorporation of ^{131}I.

Table 10 Category of Chernobyl sufferers

Category	Population	Total body dose
A. Staff of NPP and firefighters who were at the scene.	1,000~2,000	1~20 Sv
B. Liquidators (military, construction workers etc)	600,000~800,000	0.1~1 Sv
C. Evacuees from the 30km zone	120,000	Average 30 mSv*
D. Inhabitants of highly contaminated areas and resettlers	250,000~300,000	Average 50 mSv
E. Inhabitants of contaminated areas (>37 kBq/m^2)	6 million	Average 10 mSv

*; The present author considers that this value is underestimated.

✧ Cancer deaths and indirect effects

As a result of 20-years of investigations on the consequences of the Chernobyl accident, Chernobyl Forum concluded that the total number of deaths due to the accident was 4,000 people, including the future cancer deaths [6]. Following this conclusion, mass media in the world announced “The true effects of the Chernobyl accident was found to be far smaller than those previously considered.” The breakdown of 4,000 deaths is as follows: 60 deaths so far confirmed and 3,940 cancer deaths estimated by a model calculation among 200,000 people of liquidators in 1986 and 1987, 120,000 evacuees from the 30-km zone and 270,000 inhabitants in heavily contaminated areas.

This conclusion of the Chernobyl Forum was criticized by specialists from Ukraine and Belarus as well as by the Belarusian government. In addition, WHO [21] and IARC (International Agency for Research on Cancer) [22] published their own estimates that were several times larger than that of the Chernobyl Forum.

Table 11 summarizes various estimates of total cancer deaths due to the Chernobyl accident. The Chernobyl Forum gives the lowest estimate, while the highest estimate by Greenpeace [24] is more than 20 times larger than that by Chernobyl Forum. This difference reflects the fact that the number of cancer deaths largely depends on the risk model and the size of population used by the evaluator. Considering uncertainty of estimates, the present author considers that a total of 20,000 – 60,000 cancer deaths seem to be a reasonable one.

Table 11. Various estimates of cancer deaths due to the Chernobyl accident

Evaluator	Cancer deaths	Population	Cancer death risk per 1 Sv
Chernobyl Forum (2005) [6]	3,940	600,000	0.11
WHO (2006) [21]	9,000	7.4 million in three countries	0.11
IARC (2006) [22]	16,000	570 million in Europe	0.1
NGO Kiev conference(2006) [23]	30,000～60,000	Whole world	0.05～0.1
Greenpeace (2006) [24]	93,000	Whole world	—

One comment should be added about the health effects of the Chernobyl accident. Through the experience of the present author who has been involved in the study of the Chernobyl consequences for more than twenty years, it became clear that radiation effect is merely one aspect of the huge catastrophe that the Chernobyl accident brought upon. He thinks that more attention should be paid to the effects not directly related to radiation exposure. For example, it can be easily imagined what an adverse change of life would arise when the old people who had been quietly living in rural areas were suddenly obliged to evacuate to a big city such as Kyiv. Some evacuees who lost their jobs might become alcoholics in despair of their future. These cases should be recognized as indirect effects of the Chernobyl accident.

According to Scherbak Yu who gave a lecture about Chernobyl at the institute of the present author in April 2006, there were 17,000 families in Ukraine, the death of whose householder were admitted to be caused by the Chernobyl accident and receiving special privileges for it. This number suggests that indirect deaths could be far more than the direct deaths from radiation exposure.

The present author is sure that scientific approach is effective to reveal what happened. However, considering the areas is limited where the scientific approach is effective, he is also sure that our imagination should be trained in order to understand the whole picture of the Chernobyl accident.

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Current State of «Shelter» Object

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INTRODUCTION

On April 26, 1986, the biggest accident in power engineering history took place at the ChNPP Unit 4, which resulted in total destruction of reactor core, damage of reactor department, deaerating stack, turbine hall (TH) and a range of other buildings. Barriers and safety systems, which were protecting the environment from radionuclides contained within the irradiated fuel, were destroyed, and the activity was released from reactor. That release, being of some million curies per day, was occurring in the course of 10 days, from 26.04.86 to 06.05.86, thereafter it dropped at some thousand fold, and subsequently, was gradually reducing (Fig. 1).

The main «Shelter»'s peculiarity **is its remaining potential danger, much more greater, that is accepted by the norms and rules existing for the objects, that contain nuclear hazardous fissile and radioactive materials.**

As a whole, in the view of radiation safety, the «Shelter» object is an opened source of alpha-, beta-, gamma- and neutron radiation, which with its radiation characteristics has no analogues in world practices

Definition of «Shelter» object's current status is described in the addendum to NRBU-97 «Radiation protection from potential exposure sources» (NRBU-97/D-2000).

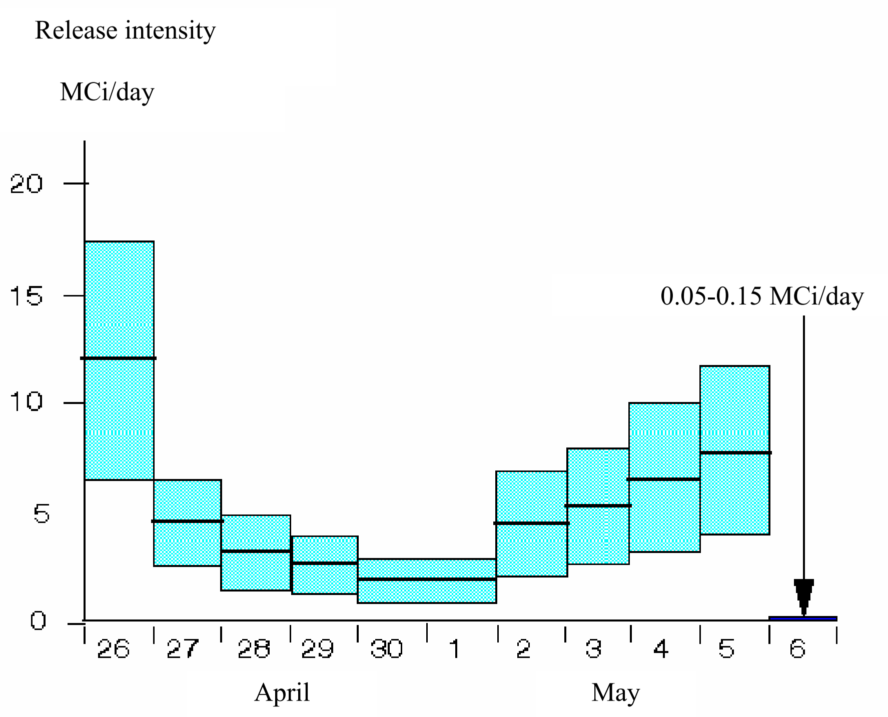

Figure 1 – Intensity of fission product release of reactor core (the first 10 days)

It reads: **«…»Shelter» object in its today conditions should be classified as *«the place for surface storage of unorganized RAW («temporary repository of unorganized RAW being in stage of stabilization and reconstruction»).***

1. UNIT 4 DESTRUCTIONS AFTER ACCIDENT AND CREATION OF «SHELTER» OBJECT

After the explosion occurred in the 26.04.86 night at ChNPP Unit 4, a part of reactor unit structures, deaerating stack, turbine hall and other buildings become ruined (Fig.2). The main damages of buildings, which it succeeded to detect during the external examination and when penetrating into accessible (due to radiation level and destruction rate) premises, were as regards:

Reactor unit.

Active core is completely destroyed. Its fragments were thrown out by the explosion into building breakdown, to the roofs of neighbouring buildings, ventilation pipe sites, scattered along adjoining territory. It was cleared up later, that a part of nuclear fuel came to bottom marks of reactor department in the shape of fuel lava.

Upper plate of biological shield (scheme «E») is torn off from its place and is standing inclined across the reactor vault. Walls and ceilings of reactor Central Hall are destroyed. Ceilings are displaced and walls of drum-separators' premises are destroyed. Reloading machine was torn off and came down. Premises of northern main circulating pumps (MCP) are completely destroyed, premises of southern MCP – are partially destroyed.

Deaerating stack.

Two upper floors are destroyed; framework columns are displaced to turbine hall side.

Turbine hall.

As a result of fire and debris collapse, roofing is destroyed in many places. Air-blast deformed several building trusses, framework columns along axis A are displaced.

Figure 2 - Destroyed ChNPP Unit 4

Unit of reactor department auxiliary systems.

It has several local destructions.

Reactor scram system.

Is completely destroyed and blocked with building structures.

Except the above main destructions, there were numerous destructions of individual structures and premises, which did not exerted any great influence to general buildings' stability.

Territory.

After the explosion occurred, the territory adjoining directly to destroyed unit was contaminated by the scattered fragments of active core: fuel rod debris, graphite stack parts, structure elements. They came to the roof and inside the turbine hall, deaerating stack, on Unit 3 roof, metallic supports of ventilation pipe, etc.

In the middle of 1986 May, the Government Commission took the decision on long-term conservation of Unit 4 aimed at prevention of radionuclides release into the environment and reduction of penetrating radiation impact at the ChNPP site.

In keeping with the CC CPSU and USSR CM Decree No 634-188 of 29.05.86, the USSR Ministry of medium machine-building was vested with "the works for burial of ChNPP power Unit 4 and related to it buildings". The facility was called as «the Shelter of ChNPP Unit 4».

1.1. «Shelter» object structure

The erection of «Shelter» was completed in 1986 November.

On November 30, 1986, the State Acceptance Inspection appointed by the USSR Council of Ministers Decree of October 23, 86, No 2126pc, accepted to the maintenance the ChNPP conservated power Unit No 4 (Fig.3, 4).

In turbine hall between the power units, 2.3-m thick cast concrete wall was erected to mark +19,0, and above – that of 1.4-m thick. In the deaerating stack, partition walls are made of 1-m thick cast reinforced concrete along the row along the row Б between the axes 41-35, and along the axis 41 between the rows Б-В.

In reactor unit, partition wall to mark +12,0 m between the rows Т-Л is made by the way of filling with concrete of transport corridor between the axes 41-42. In other places, existing walls and partitions

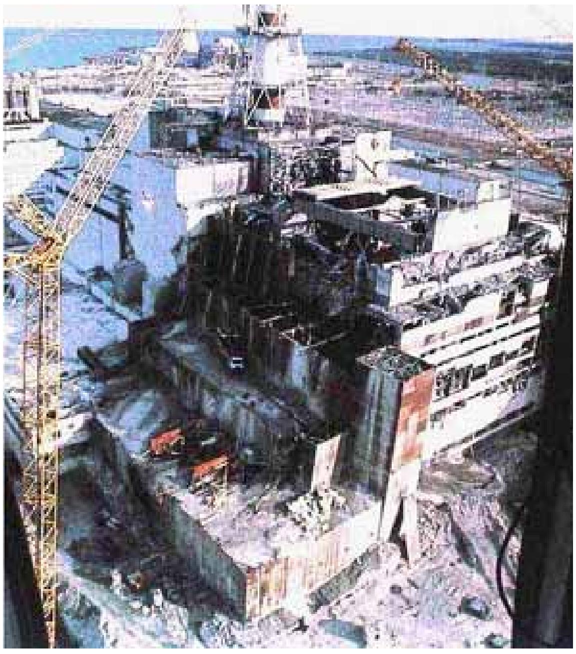

Figure 3 – Erection of «Shelter» object

Figure 4 – A view of «Shelter» object

after appropriate filling up of apertures, openings, cracks, etc., were used.

Along the Unit 4 perimeter, at first «pioneer» protective ferroconcrete walls were made of height:

- around 6 m from obstruction side (northern unit side);
- around 8 m from southern and western side.

Northern cascade wall was made of concrete in the shape of around 12-m high projections.

Preserved western wall from the outside is closed with the wall having 50-m high buttresses.

To support the main B1/B2 beams installed along the П and Ж rows, around 0,9-m thick debris of ferroconcrete wall at western part were used along axis 50, and ferroconcrete ventilation shafts near the axes 43-44, which preserved after explosion.

Damaged wall site within the area of row Ж before the beams installation is reinforced by steel stay with its subsequent concreting.

Over B1/B2 beams, 27 metallic tubes of 1220-m diameter and 34,5-m length are laid, and over the tubes - the roofing is made of profiled deck – 6 spatial units.

As a support for steel boards in southern side, steel «Mammoth» beam serves, which is installed along the row B, and which, in its turn, rests upon concrete bearers near the axes 41 and 51.

The bearers were made on an obstruction of destroyed ferroconcrete structures of ceilings of two upper floors, equipment and pipeline debris.

For the ceiling of unit site between the axes 40-50 in rows Б-В along the row Б supporting on the another ceiling that was obstructed by destroyed structures, chest beam was designed and manufactured («Octopus»), which serves as a distributing structure.

Over the turbine hall (TH) in the axes 40-50 between the rows А-Б, a new roofing is designed to be made of beam-trusses and steel boards resting, along the row A, upon newly installed spatial columns and preserved cantilevers in columns along the row B. Between the axes 54-50 and 40-34, spatial steel units on existing coating are laid.

2. NUCLEARLY HAZARDOUS MATERIALS INSIDE THE «SHELTER» OBJECT (INTEGRAL ESTIMATES)

2.1 Nuclear fuel located inside Unit 4 before the accident

Before the accident, nuclear fuel was located in four places of Unit 4 reactor department:

- in active core of RBMK-1000 nuclear reactor;
- in pool for exposition of spent fuel cassettes;
- at site for preparation of fuel cassettes in Central Hall;
- in premises for preparation of fresh fuel.

Distribution of nuclear fuel before the accident is shown in the Table 1.

Table 1 - Location and amount of nuclear fuel in Unit 4 reactor department premises before accident

Premises	Technological assignment of premises	Nuclear fuel amount on uranium, t
504/2	Reactor vault	*190.2
505/3	Southern cassette exposition pool	**14.8
914/2	Central hall	**5.5
503/2	Premises for fresh fuel preparation	**· ***4.1
Total		**214.6

* - to accident moment, reactor active core contained 1659 fuel assemblies (FA), 1 additional absorber (AA) and one unloaded fuel channel. Major part of FA represented the cassettes of first loading with burnup being 11 - 15 MWt · day/kg (U). The core also contained some amount of fresh fuel. Uranium mass in each cassette made up – 0,1147 t. Total mass of fuel loaded in active core, made 190,2 t.

** - data are taken from “Certificate of nuclear fuel amount at Chornobyl NPP Unit 4 at accident moment”, confirmed by Chief Engineer of IA ChNPP on 30.01.96. Besides, the data on fuel amount in exposition pool are delivered on the basis of log for registration of NSD and NM, and in Central Hall and premises 503/2 - on the basis of «Certificate for write-off of fresh nuclear fuel from Unit 4 of 26.04.86».

*** - nuclear fuel from preparation premises (premises 503/2) was removed in 1986 (after accident) to ChNPP fresh fuel storage.

2.2. Fuel-containing materials that are currently located in «Shelter» object premises

Currently, inside the «Shelter» object, there are nuclear fuel modifications, which produced in the course of proceeding of accident active stage and during interaction of that fuel with structural materials, dynamic and thermal impact of explosion, as well as during oxidation of uranium dioxide when contacting with air oxygen before and after the reactor burning.

Such modifications include as follows:

2.2.1. Active core fragments

During the mitigation of accident aftermath, a part of active core fragments (ACF) representing fuel pellets, debris of fuel rods, fuel assemblies, graphite, located around the building, was displaced to the breakdown and thereafter buried in cascade wall, a part is collected in containers with high-level waste, another part is buried under the layer of concrete and crushed stone strewn near the Unit. Destroyed fuel that was released on buildings roofs and pipe sites, was thrown down in reactor ruins (Fig.5).

Significant ACF amount must be located in the CH and premises 305/2.

Figure 5 – Premises 305/2. Southeast sector. Active core fragments

2.2.2. Lava-like fuel-containing materials (LFCM)

Lava-like materials containing nuclear fuel were detected in many subreactor premises (Fig.6-7). They contained a significant part of uranium located before the accident in active core, and a considerable part of radionuclides, which were produced in reactor.

LFCM represents a heterogeneous solid solution, whose «dissolvent» is vitreous silicate matrix with great amount of diverse impurities, among which uranium oxides, uranium-zirconium-oxygen phase (so called "chernobylite"), and metallic globules are encountered.

Uranium percentage within the LFCM fluctuates within the range from 5 to 10%.

Figure 6 – Lava in steam discharge valve of SDC

2.2.3. Total amount of nuclear fuel in different premises of «Shelter» object

Integral estimate of current nuclear fuel amount in different premises of «Shelter» object are shown in Table 2.

Figure 7 – Lava in PSP-1

Table 2 – Fuel amount estimates in «Shelter» object premises

Name (numbers) of premises	FCM modifications in premises	Detected fuel, t (U) (estimates for year of 2004)	Notes
Central hall (914/2)	active core fragments	more 21	Considering 48 assemblies with fresh fuel (5.5 t) Is possible LFCM presence
Southern exposition pool (505/3)	active core fragments	14.8	129 spent fuel cassettes. Is possible LFCM presence
All upper premises, including CH (mark +24.00 and above)	fuel dust	~5 on obstruction surface in CH, ~30 total	Estimate 30 t includes surface contamination inside obstruction in CH and in all other premises
304/3	LFCM	6 ± 2	«Horizontal lava flow». FCM are included in breakdown between prem.304/3 and 305/2.
301/5+301/6+303/3	LFCM	4.5 ± 2.5	«Horizontal lava flow»
217/2	LFCM	0.4 ± 0.2	«Elephant foot», «stalactites». LFCM came from «horizontal flow».
Subapparatus 305/2 and 504/2 before mark 24m.	fragments of AC, LFCM, dust	85 ± 25	Estimates were made for 6 FCM clusters. Origin of all LFCM flows.
SDC (210/5+210/6+210/7)	LFCM	12 ± 6	«Big vertical flow» and «small vertical flow»
PSP-2 (012/14+012/15+012/16)	LFCM	minimum - 3, maximum - 14	
PSP-1 (012/5+012/6+012/7)	LFCM	1.9 (+1.0; -0.5)	
Fuel under cascade wall	fragments of AC, dust	?	
Water in all premises of reactor department	soluble uranium salts, dredge.	~4 kg	
Fuel at «Shelter» site	Fragments AC, dust	0.75 ± 0.25	

Specific activity of some emitters for base fuel content of power Unit 4 for 01.02.2005 is shown in Table 3

Table 3 - Specific activity of some emitters for base content of power Unit 4 fuel at 01.02.2005, Bq/g uranium

Alpha-emitters	Beta-emitters	Beta-gamma-emitters
Pu-238 --- $6.7 \cdot 10^{6}$	Sr-90 --- $7.60 \cdot 10^{8}$	Rh-106 --- $1.29 \cdot 10^{4}$
Pu-239 --- $5.0 \cdot 10^{6}$	Y-90 --- $7.60 \cdot 10^{8}$	Sb-125 --- $7.12 \cdot 10^{5}$
Pu-240 --- $8.19 \cdot 10^{6}$	Ru-106 --- $1.29 \cdot 10^{4}$	Cs-134 --- $1.61 \cdot 10^{6}$
Pu-241 --- $9.32 \cdot 10^{3}$	Pm-147 --- $2.65 \cdot 10^{7}$	Cs-137 --- $9.09 \cdot 10^{8}$
Pu-242 --- $1.30 \cdot 10^{4}$	Pu-241 --- $3.89 \cdot 10^{8}$	Ce-144 --- $1.20 \cdot 10^{3}$
Am-241 --- $1.95 \cdot 10^{7}$		Eu-154 --- $1.64 \cdot 10^{7}$
Am-243 --- $8.73 \cdot 10^{3}$		Eu-155 --- $4.45 \cdot 10^{6}$
Cm-244 --- $1,07 \cdot 10^{6}$		
In sum ≈ 80 Ki/kg uranium		

Thus, total activity of fuel currently located in «Shelter» object makes around 14 MCi.

3. WATER LOCATED IN «SHELTER» OBJECT PREMISES

One of the main sources of radiation hazard in the object is the water. Water influences the nuclear safety conditions, thus leading to change of reproducing system «FCM+water». Water interacting with the FCM dissolves and transports radionuclides, which, as a result, can come into the environment.

Water coming to the SO in the shape of atmospheric precipitation, condensate and dust-suppressing solutions, moving from upper marks to the premises at SO bottom marks, washes FCM cluster and contaminated surfaces of structural materials. As a result of that processes, high-level alkali-carbonate solutions are produced, representing, practically, liquid radioactive waste. LRW leakings produce permanent and temporary LRW clusters at Unit bottom marks. It is stated that between many LRW clusters exist hydraulic connections.

Northern LRW flow

Northern LRW flow, whose consumption makes 700 – 800 m3/year, passes through the premises 001/3, where the biggest LRW cluster is localized (Fig.8, point 30). In that premises, numerous leakings are collected from central and northern part of units «B» and RDAS, as well as from the cascade wall side. Further, SO LRW flow percolates through partition wall into Unit 3 RDAS premises, and, finally, comes to premises 0005 sump (Fig.8, point 111). As soon as the sump is filled, LRW is pumped out in ChNPP chemical shop for temporary storage and treatment. Practically, northern LRW flow represents naturally «averaged» leakings from central and northern part of Units «B» and RDAS.

Southern LRW flow

Southern LRW flow, whose consumption does not exceed 300 m^3/year, passes through the

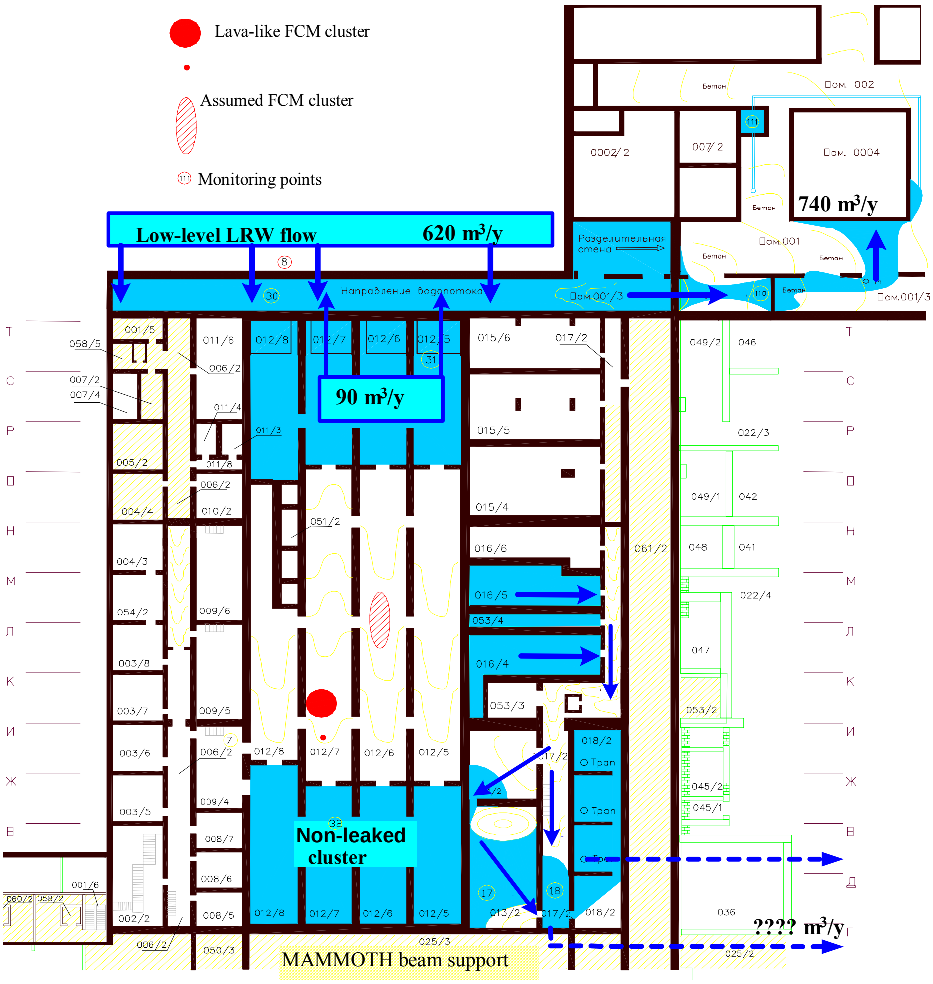

Figure 8 - SO LRW clusters and flows in pressure suppression pool (mark –0.650) and RDAS unit premises (mark –2.600 and – +6.000)

premises 017/2 and 061/2 and produces sufficiently large clusters in southern part of that premises (Fig.8, point 18). Water level in this premises is permanent – under intensive inflow, water excess spills over the threshold in premises 018/2, where special sewer system traps are located, or percolates in premises 025/2. In premises 061/2, water level depends on the season – in condensation period, the level increases, in dry period, as a result of evaporation, it reduces. Pathways of LRW leaking from that premises are not defined.

Radionuclide and chemical content of LRW

LRW radionuclide content at Unit bottom marks is formed as a result of interaction of atmospheric precipitation, condensation moisture and technogenic solutions with the following nuclear fuel modifications, which were produced during the accident:

- «hot» particles of condensation type;
- dispersed fuel in the shape of UO_2 and U_3O_8;
- lava-like fuel-containing materials.

Hot particles of aerosol-condensation type define at a significant rate the level of surface contamination of internal premises of «Shelter» object, besides, currently, the biggest contribution into activity is made by ^{137}Cs and ^{125}Sb isotopes. As a result of these particles dissolution, water contamination occurs with caesium isotopes. The main source of «unit» water contamination with fissile elements and ^{90}Sr are oxidated fuel particles (U_3O_8). Chemical stability of oxidated particles in relation to water is lower, than that of initial fuel (UO_2) and, moreover, of lava-like FCM.

Table 4 – Average concentrations of radionuclides and uranium in SO LRW main clusters

Point numb.	Mark m	Number of premises	Volume m^3	Component concentration, Bq/l				
				^{137}Cs	**^{90}Sr**	**Σ Pu**	**^{241}Am**	**ΣU, mg/l**
6	+ 2.20	012/16	60 m^3	$6.2*10^7$	$9.9*10^6$	4000	$1.7*10^4$	48
-	+ 6.00	219/2	10 m^3	$4.0*10^6$	$1.0*10^5$	-	-	1.1
17	- 0.65	017/2	7 m3	$5.0*10^6$	$1.0*10^5$	-	-	8.9
18	- 0.65	013/2	20 m^3	$4.0*10^6$	$0.8*10^5$	-	-	1.1
30	- 2.60	001/3	270 m^3	$5.2*10^6$	$1.0*10^6$	360	$4.0*10^3$	3.6
31	- 0.65	012/5	20 m^3	$6.1*10^7$	$8.9 *10^6$	3100	$1.3*10^4$	43
32	- 0.65	012/7	10 m^3	$1.3*10^8$	$2.2*10^6$	4200	$2.8*10^4$	110
111	- 6.00	0005	5 m3	$6.8*10^6$	$1.0*10^6$	1600	$2.0*10^3$	5.7

Atmospheric precipitation, technogenic solutions and condensate during movement from upper marks to bottom ones leach the most soluble concrete components – carbonates, bicarbonates, chlorides and sulphates of alkaline metals. Heavy metals transfer to a solution due to metal structures corrosion. As a result of these processes, formation itself of radionuclide, chemical and phase content of «unit» water occurs. Averaged radionuclide content and activity of main water clusters and flows of «Shelter» object is shown in Table 4. A part of this activity is concentrated in silt sediments, and depending on dryout rate in summer-autumn period, poses a treat as aerosol source.

4. FUEL AT «SHELTER» OBJECT INDUSTRIAL SITE

During the accident and works for mitigation of its aftermath, ground layer produced at the site around ChNPP Unit 4, contaminated by released radioactivity. One could succeed to remove it only partially, for site decontamination purposes the active ground was covered with clean materials. As a result, an original «sandwich» produced, in which the materials were located in the following order (from depth - to surface):

initial ground (pre-accident) – active layer –coating materials.

It seems as important to study the active layer because of several reasons:

- it may contain considerable fuel amount ;
- displacement of active layer under the influence of natural factors can lead to ground waters contamination;
- conversion of «Shelter» into an ecologically safe system will demand performing works at the Object industrial site, during which the active layer is to be touched upon, that is why one should have maximally full information about it.

As analysis of new data shows, active layer thickness in local zone is predominantly laying within the range of 10 – 30 cm. Total ground volume is estimated (according to value order) at 15000 m^3.

Applying the research data and drilling the boreholes, it is offered to take as an expert estimate the fact that the fuel amount in local zone makes (0.75 ± 0.,25) t.

5. RADIOACTIVE AEROSOLS OF «SHELTER» OBJECT

Air migration of radionuclides from the «Shelter» object is one of the main sources of environmental contamination under normal operation, and, especially, during the accidents.

Radioactive particles located in the «Shelter» object can be (very roughly) divided into two types – condensation and fuel ones.

The first particles type was produced as a result of condensation of radionuclides having relatively low boiling temperature and coupled from the fuel during accident active stage on particles of dust, soot, graphite, building structures, etc.

The second particles type – fuel particles produced during fuel dispersion and containing isotopes of plutonium, americium, and curium. They can be comfortably divided into two subtypes: «large» fuel particles with size from dozen and hundred micron and «small» fuel particles with average median diameter of 3-4 microns.

Most hazardous in terms of radiation safety are «small» fuel particles.

When performing the works in the «Shelter» object premises, concentration of alpha-active aerosols can reach 10^4 admissible concentrations.

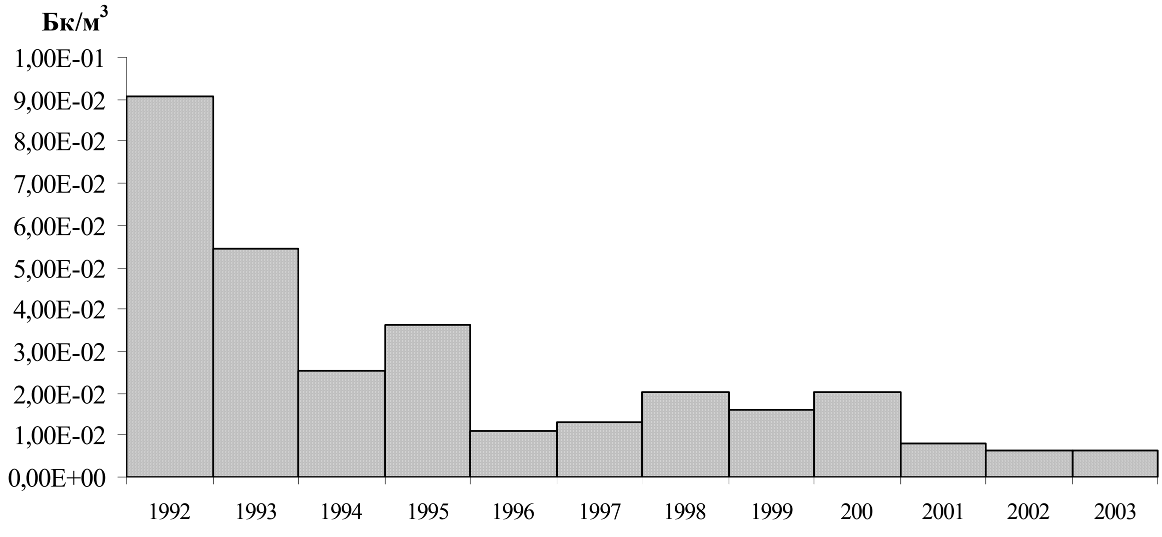

Figure 9 - Estimates of annual volumetric summary alpha- beta-activity in near-surface air aerosols of «Shelter» object local zone using aspiration facility data

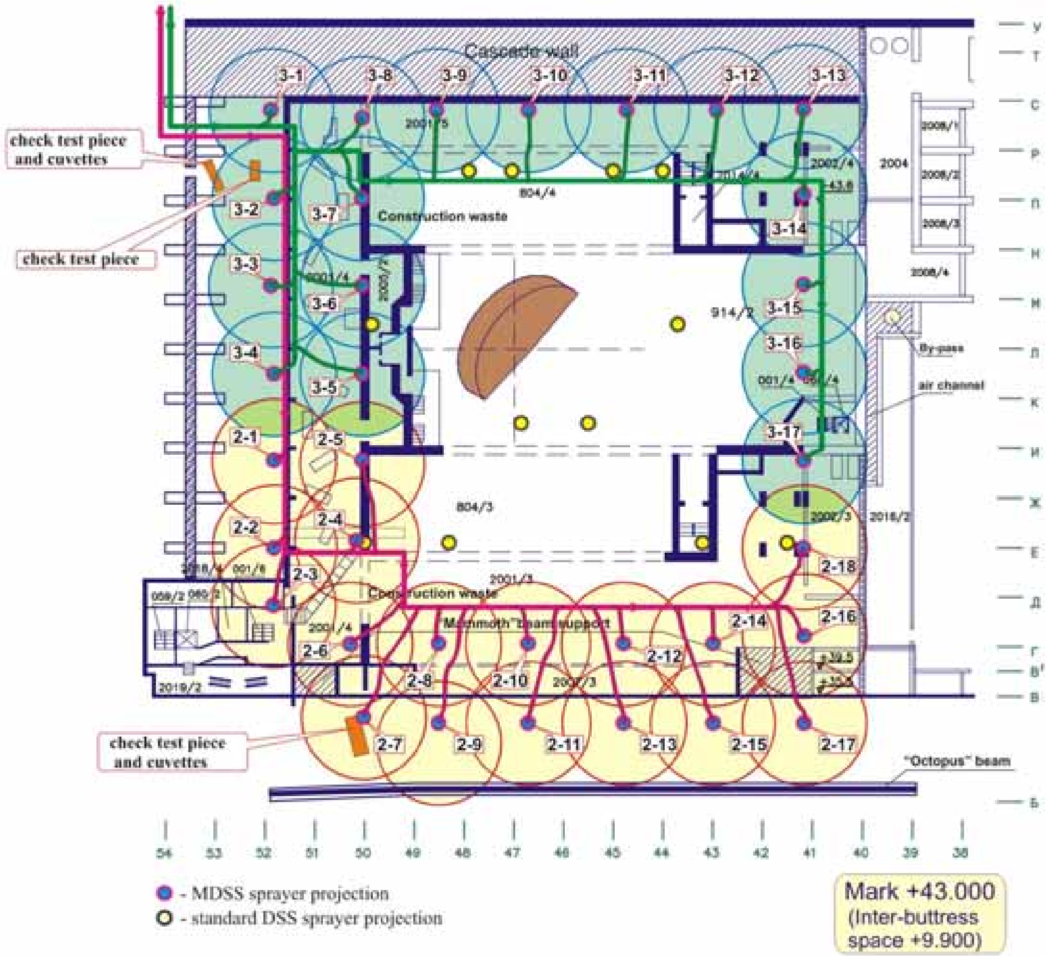

Figure 10. Scheme of location of collectors and zones covering upgraded DSS.

In order to reduce aerosols concentrations in the «Shelter» object and their release into atmosphere, stationary dust suppression system (DSS) was commissioned in 1989 end, which includes the system for preparation and supply of dust-suppressing compositions through 14 nozzles located over «Breakdown» surface of central hall. Since December 1989 till now, more 1 000 tons of dust-suppressing compositions were laid, that allowed significantly reducing and stabilizing the aerosols release from the «Shelter» object (Fig.9). To increase regular DSS efficiency, it was upgraded, which included assemblage of two additional collectors and 35 nozzles covering the perimeter of sub-roofing space and the space between Unit 4 western wall and buttress wall (Fig.10).

6. SYSTEMS FOR NUCLEAR SAFETY MONITORING

Obtained recently experimental information on distribution, configuration and composition of spent and fresh nuclear fuel for «Shelter» object individual premises does not possess the accuracy, which would be sufficient for substantiated forecast of nuclear safety.

In existing conditions, in terms of nuclear safety provision, the «Shelter» object represents a spatially distributed uncontrollable cluster of nuclear hazardous fissionable materials without emergency protection means.

In current real conditions, the FCM, when moderator is absent, are subcritical ones. However, generation of self-sustained fission chain reaction is not excluded when pouring with water the FCM with great enough fuel heterogeneity.

Currently, to monitor «Shelter» object nuclear safety, readouts of following systems are used:

- information-measuring systems (IMS) «Finish-R», which monitors the FCM conditions (thermo-physical and nuclear-physical parameters);

- FCM monitoring systems (СК FCM) «Signal».Such a configuration was formed relatively not long ago. Complex «Finish-R» is set up as an autonomous system after withdrawal in December 1998 from the structure of research system «Finish». Appropriate operation documentation was designed for it, and metrological certification of measuring channels and hardware was made.

Since 1998, system "Signal" was accepted in pilot-industrial operation. According to its results, the system was adopted as meeting technical documentation and transferred to normal operation mode (technical decision IA ChNPP of 26.03.2000).

7. RADIATION PARAMETERS OF «SHELTER» OBJECT

7.1 General characterization of radiation state of Object premises

Exposure dose rates (EDR) in internal premises and on «Shelter» roofing are within a very extended range. Thus, a need appears in introducing special classification of industrial, administrative, storage facilities and other premises and territories – to split them into zones due to radiation hazard rate.

Such a classification is realized in the document - "Provision of zoning "Shelter" object premises (2003 year).

In this document, the notion "subzone" is introduced and all the premises are split into three groups, depending on EDR value in them:

«1 subzone» — unattended premises; gamma radiation EDR > 3,3 mR/hour.

«2 subzone» — premises of periodical stay of personnel, gamma radiation EDR 3,3 - 1,6 mR/hour.

«3 subzone» — premises of permanent stay of personnel; gamma radiation EDR < 1,6 mR/hour.

Currently, distribution of «Shelter» premises due to EDR value looks like as follows (see Table 5, compiled on the basis of "Provision of zoning…»).

Table 5 - Distribution of investigated «Shelter» premises» on EDR level

Radiation conditions, R/hour	Units				
	Unit «Б»	Unit «В»	Unit RDAS	Unit «Г» (А-Б)	Unit «Г» (Б-Г)
to 0,5	66	17	59	59	140
0,5 – 1	13				1
1 - 5	70			6	1
5 - 10	7			1	
10 – 50	14				
50 – 100	7				
100 – 500	4				
> 500	7				
Inaccessible premises	126		4	28	7

The Table shows that in majority of accessible premises of reactor Unit «Б», the mean value of gamma-radiation EDR does not exceed 1 R/hour. So, inside of more 60 of them, the EDR is lower 0,5 R/hour.

Those premises are excepted, in which fuel-containing materials have penetrated. That premises are characterized by availability of heterogeneous, with high gradients, gamma-field EDR defined by FCM spatial location in premises and by uranium content in FCM and its fission product. Thus, EDR values in premises 305/2 - 1800 R/h (mark +12.200, row $И_{+1200}$, axis 46_{+2800}) and 1 – 3 R/h (near aperture of northern sliding gate).

The premises 304/3 floor is completely filled with LFCM layer, EDR value in premises - 50 - 350 R/h. EDR value on «heap» of 1-st floor of pressure suppression pool (prem. 012/7) makes around 400 R/h, 10 m northward – around 2 R/h. EDR over open laying LFCM of premises 210/6 SDC ($И_{+1500}$, 47_{-400}) – 300 R/h and 0,2 – 0,5 R/h over concrete surface in northern part of this premises. In central hall within the area of scheme «E» at mark +39.000 the EDR value makes 280 R/h, at mark +49.000 – 30 R/h.

7.2 Radiation conditions on «Shelter» roofing

After explosions, roofing over CH, premises of southern and northern drum-separators, practically ceased its existence. On neighboring roofing, numerous active core fragments were released –assembly parts, graphite, metallic structures elements, etc. Later, during the active stage, considerable amount of fuel dust dropped on them.

Immediately after «Shelter» erection, radiation conditions on its roofing was defined, mainly, by gamma-radiation penetrating from internal premises and coming from neighboring structures. It is clear seen considerable EDR reduction, which occurred as a result of natural decay of emitters and large complex of decontamination works carried out on the roofing.

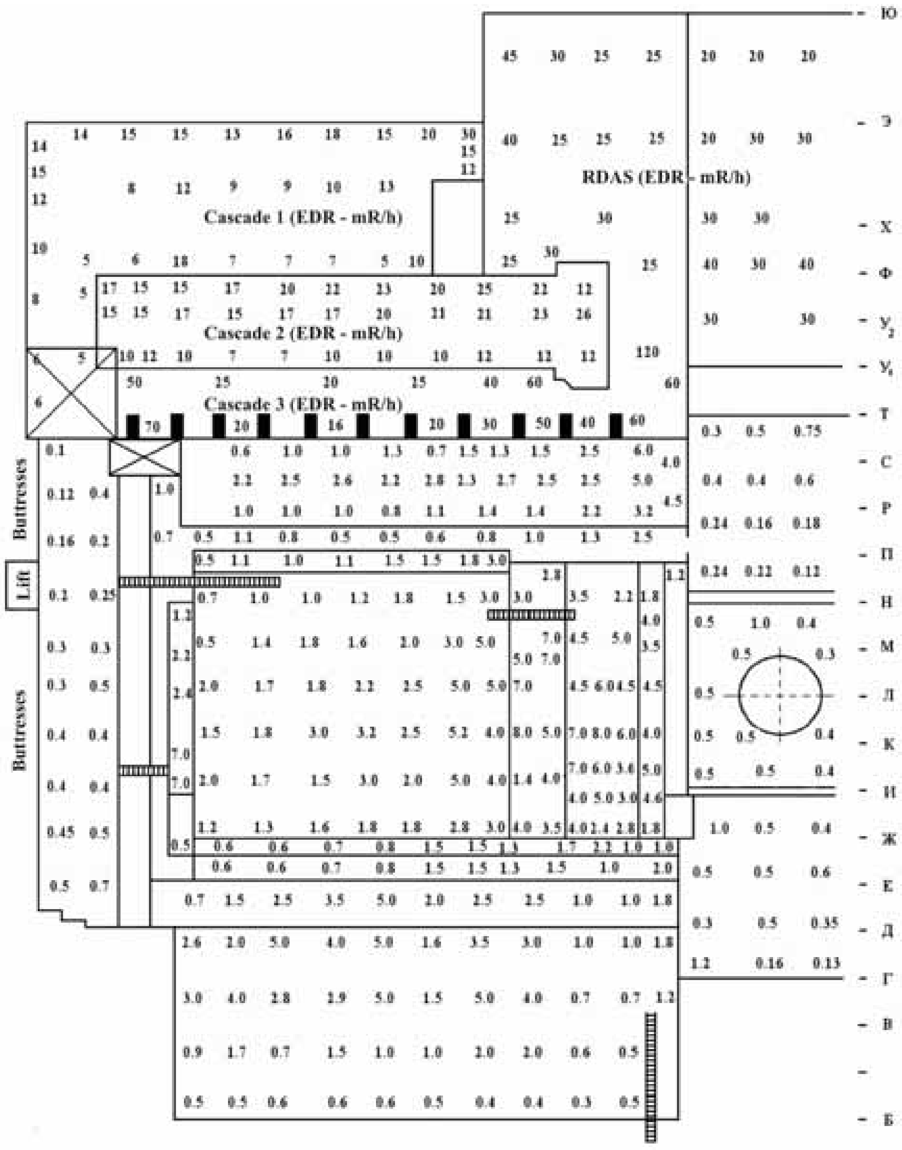

Figure 11 - Chart of EDR value on «Shelter» object roofing in the axes 35 – 54, rows Б – Ю

Eventually, in «Shelter» roofing contamination, a great role began playing radioactive dust released from the building through technological openings and coming from neighboring contaminated roofing.

Results of radiation conditions measurement on the roofing, which were made in June 2000, the Fig.11 illustrates.

7.3 Contamination rate of premises surfaces and territory

The idea of total contamination rate of surfaces in «Shelter» object premises, BK-3, RDAS, as well as of roads and pavements at industrial site territory is shown in Table 6.

Table 6 - Contamination rate of premises and territory

No	Monitored object	α - contamination rate (readout) $\frac{particles}{cm^2 \times min}$		β - contamination rate (readout) $\frac{particles}{cm^2 \times min}$	
		fact	RL	Fact	RL
1	RDAS unit (premises of personnel permanent stay)	1	1	2÷3	100
2	BQ-3 («clean»)	0	0	0	0
3	BQ-3 («dirty»)	0	1	0	100
4	premises of periodical personnel stay (4 unit)	0÷5	10	10÷150	500
5	premises of personnel permanent stay (4 unit)	0÷1	5	10÷50	200
6	territory (surfaces of roads and pavements inside industrial site)	0	1	20÷100	200

7.4 Radiation conditions at industrial site

EDR at territory close to the SO is defined by two factors: gamma-radiation of «Shelter» itself and emanation of radioactively contaminated grounds and objects located at SO industrial site.

The most contaminated is territory in close vicinity to ChNPP Unit 4, so called local zone of «Shelter» object. Distribution of exposure dose rate in local zone of SO industrial site is shown in Fig.12.

The chart of EDR distribution demonstrates that the contamination of territory has heterogeneous character. Analysis of EDR chart gives a reason to assume the existence of notable contribution of radiation from the SO side from the area of staircase-elevator unit. However, such evident influence is well observed only in a place being close to the SO.

SO influence onto volumetric EDR distribution over industrial site is well illustrated in Fig.13.

Gamma-field intensity increases in eastern direction (when approaching to «Shelter» object) and grows with more height.

Abrupt growth in direction to Unit is observed within the area of row A. One can assume that a cause of above abnormality can be local intensive gamma-radiation sources located on the roof of turbine hall and deaerating stack.

8. Carried out and planned SO stabilization measures

«Shelter» object is a unique spatial building, whose structural scheme represents a combination of two constituents:

- «old» structures of destroyed power Unit 4;
- «new» structures erected in the year of 1986 during «Shelter» construction.

Post-accident conditions of power Unit 4 «old» structures are characterized by total or partial destruction, large damages of remained intact elements and junctions, overloading of weight of structures obstructions and equipment collapsed on them, as well as the materials, that were used during accident mitigation period. Bared armature and metal structures are subject to corroding processes. Availability of

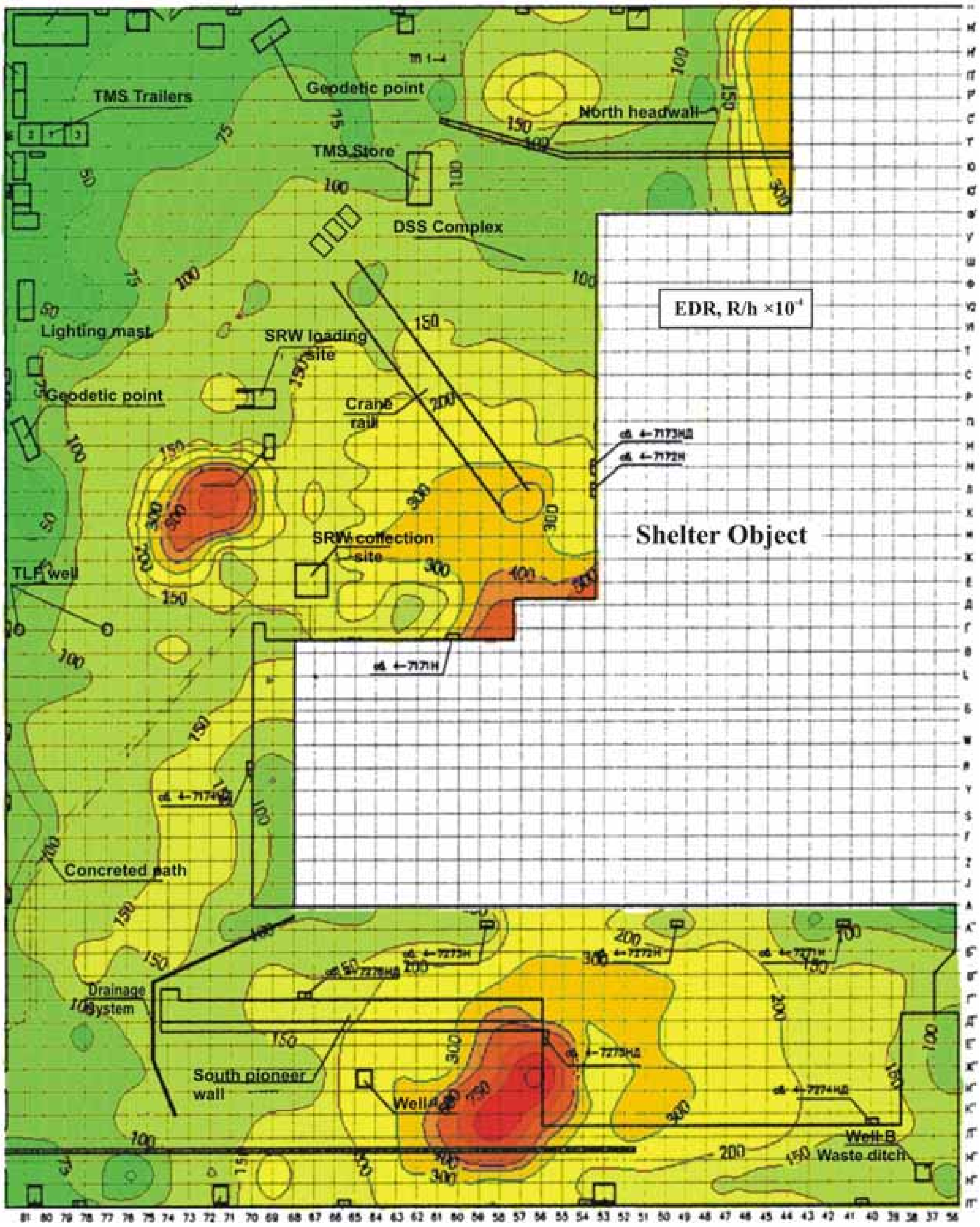

Figure 12 – Chart of exposure dose rate distribution in local zone as of January 1, 2002.

such serious defects requires permanent survey over conditions of these structures and taking, in case of need, of stabilization measures.

The «new» structures that were erected after the accident (protective-partition walls and coating's metal structures) were designed in conformity with norms and rules of structural design valid in that time period. However, for this group of structures also the problems exist of their reliability and longevity provision that conditioned by following reasons:

- technologies of remote assemblage and concreting in complicated radiation conditions that were applied, restricted possibility to control the quality of work production ;

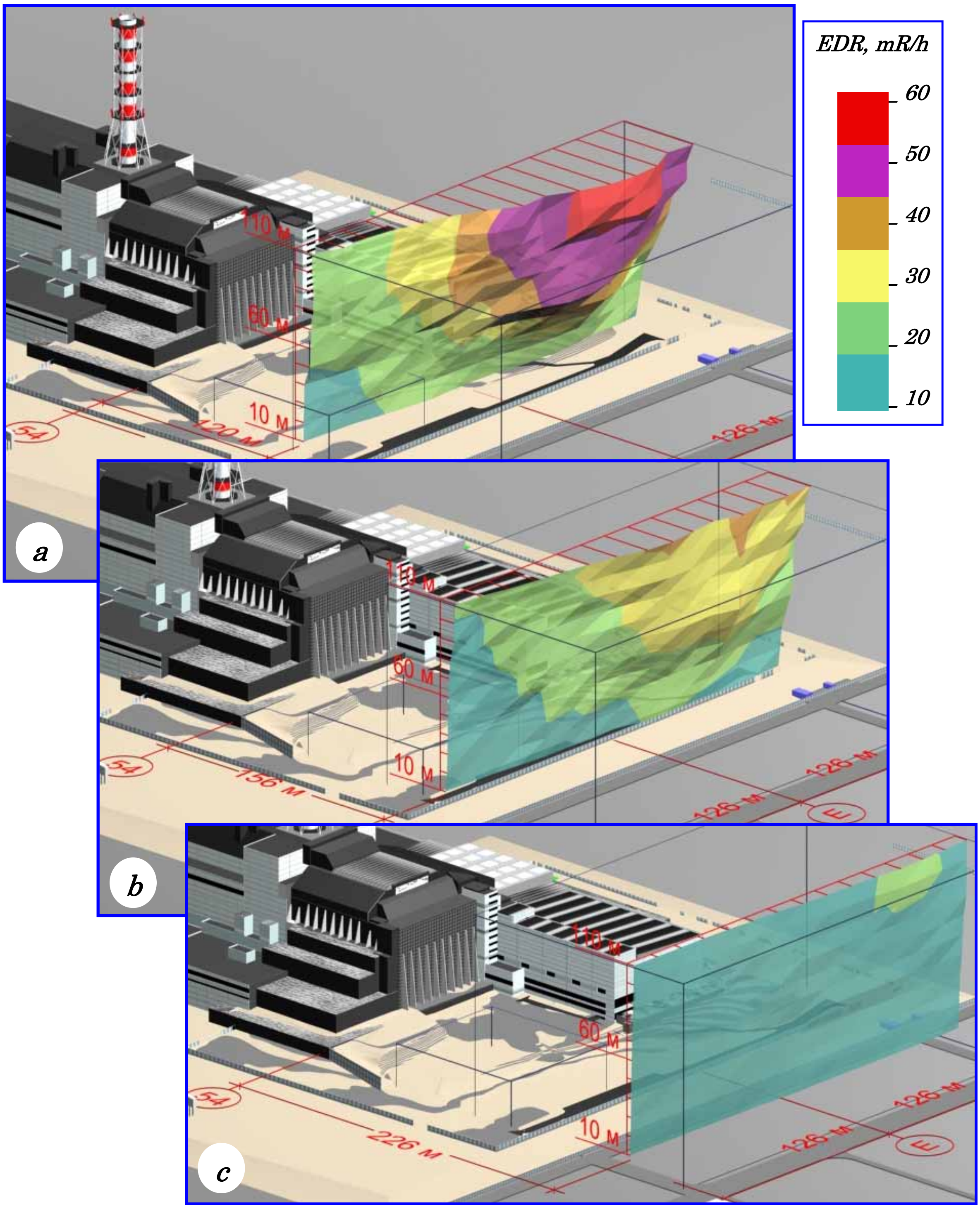

Figure 13 – Model of gamma-field in NSC erection zone (June 2004)
***a** – cross-section along axis 54 + 120 m;*
***b** – cross-section along axis 54 + 156 m;*
***c** – cross-section along axis 54 + 226 m*

- structural elements are fragmented – not connected one to another, rest freely upon bearing structures without physical connection and are retained in designed position due to friction forces (i.e. welded-, bolt or other strengthenings of support parts are absent);
- access is embarrassed to elements and metal structures joints for periodical survey and recovery of anticorrodent coating.

The first document, in which a general estimate was given of «Shelter» building structures conditions, was the «Conclusion on reliability and longevity of coating's structures, as well as on radiation safety of reactor department of Chernobyl NPP Unit 4», set forth by Government Commission on October 11 1986 to special commission of USSR Gosstroy.

The «Conclusion …» included as regards:

«Considering low corrosion velocity within the conditions of structures work, under performed protective coatings, one can regard as provided their service life:

- for pipes 30-40 years,
- for beams 30 years».

Unfortunately, in later period these figures, as it were legalized not only for service life of newly erected metal structures, but also for all «Shelter» object as a whole. Often the time of 30 years was indicated in documents, as guaranteed time for safe conditions of «Shelter» object.

At the same time, the mentioned «Conclusion…» had as written:

«In connection with the fact that the shelter of reactor department is being erected on destroyed structures and within the conditions of high radiation levels, it does not seem as possible to obtain reliable data on their bearing capacity, as well as, considering the complexity of structures installation and control of their position..., that leads to essential reduction of bearing capacity of remotely assembled structures...».

So, the main conclusion was that within the conditions, in which the Object was erected, it is impossible to reliably assess its longevity.

That is why immediately after the construction was completed, the works started for research of reliability and additional strengthening (stabilization) of «Shelter» basic bearing structures.

As a whole, three main stages of such works can be distinguished.

During the first stage (1987 – 1991), researches and certification of accessible premises were conducted, and zones of emergency conditions of building structures, which influence the «Shelter» general stability and integrity, were identified.

Three zones were identified that demand conduct of immediate anti-damage works: deaerating stack (premises 635/3), premises for MCP motors (premises 402/3), premises for exhaust ventilation air ducts (premises 805/3).

When surveying the upper tier of deaerating stack framework (rows Б-В axes 41-51) it was stated as regards: columns between the marks +24.27 and +38.60 inclined from vertical to turbine hall side at value 700 - 1100 mm. In places of column junction in mark level around +24.30, fractures produced with around 150-mm wide crack opening, longitudinal effective reinforcement had broken, crack penetration depth into column cross-section depth made 0,6 - 0,9 m. Rigid joint couplings of column and girder were also destructed, that is confirmed by rupture of upper effective reinforcement rods of extended zone and girder shift from supporting cantilevers into mark level +38.60 at 70 - 150 mm. Simultaneously, on the ceiling (above mark +38.60), obstructions of building structures, equipment and materials produced, which were used during the mitigation of accident aftermath, of height being 3...5 m.

Such conditions of upper tier framework structures of deaerating stack were classified as emergency one. Seriousness of situation was conditioned by the fact that the damaged columns along the row Б were overloaded due to leaning against them coating's structures over turbine hall. Destruction of columns would provoke a collapse of this coating, as well as of other metal structures of «Shelter» southern part («Octopus» beam, southern boards-"clubs"). Under a more unfavourable situation development, collapse of «Mammoth» beam supports and a probability of subsequent collapse of metal structures of central hall coating were not excluded.

Based on data collected on conditions of upper tier framework structures of deaerating stack, strengthening of upper zone of ferroconcrete columns of row Б was operatively realized by way of installation of inclined tensions made of two channel bars No 16 welded to dearator tanks filled with the concrete. Simultaneously, knees made of two channel bars No 24 were installed to strengthen the center of girder span in mark level +38.60 (Fig.14).

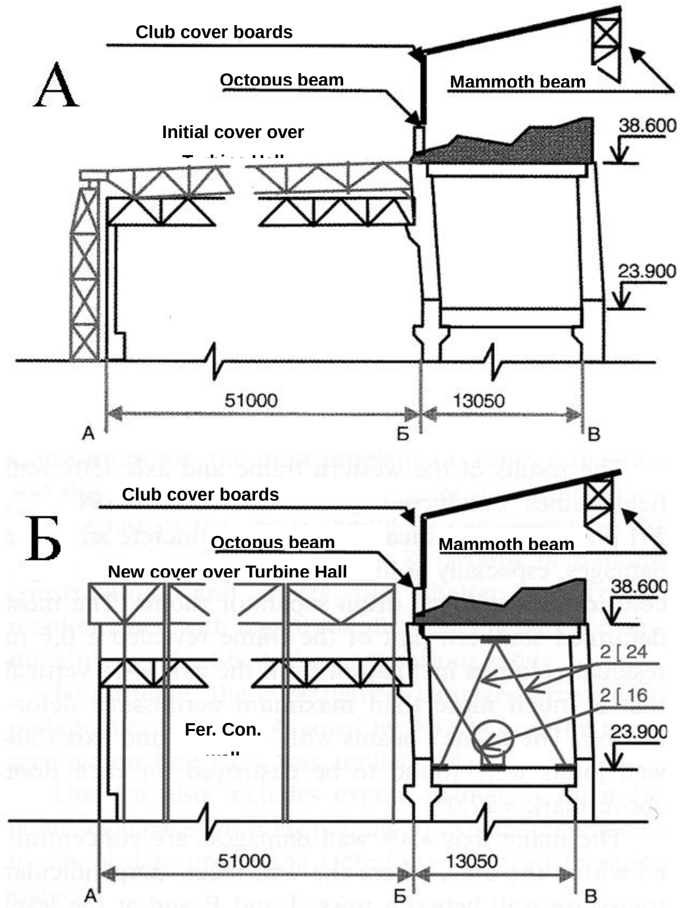

Figure 14. Structures, which strengthen deaerating stack framework:
А - pre-strengthening conditions;
Б – post-strengthening conditions.

Besides, in 1988, trusses of turbine hall coating were dismantled, which were resting upon the cantilevers of row Б columns (design decision of 1986), and instead of them the new coating was assembled with resting upon steel-concrete walls, newly erected in turbine hall between the rows А-Б along axes 41 and 49.

As a result of examination of MCP motors premises (premises 402/3) between the rows Г-Е axes 41-50, it was stated, that wall and columns along the row Г had inclined to row В side of deaerating stack. In the level of supporting cantilevers (mark +30.30), the columns displaced to row В side at 400...600 mm. In coupling joints of girders with the columns, ruptures of upper rods of girder armature and considerable concrete breakoffs were observed.

Column framework and ceiling conditions (mark +31.50) over premises 402/3 of southern MCP motors also was recognized as emergency ones.

The strengthening of indicated ceilings concluded in strengthening the supporting sites of girders and was realized by means of installation of the supporting steel structures under girders within the area of their resting upon the column cantilevers (Fig.15). The strengthening structures represented bearing steel trusses, united in spatial units by system of horizontal and vertical connections, and thereafter were remotely slided in designed position along existing crane railways of bridge crane using the winches.

As a result of examinations it was stated that the ceiling (mark +35.50) over premises of exhaust ventilation air ducts (premises 805/3) between the axes 40-50, rows В-Е, is also in emergency condition

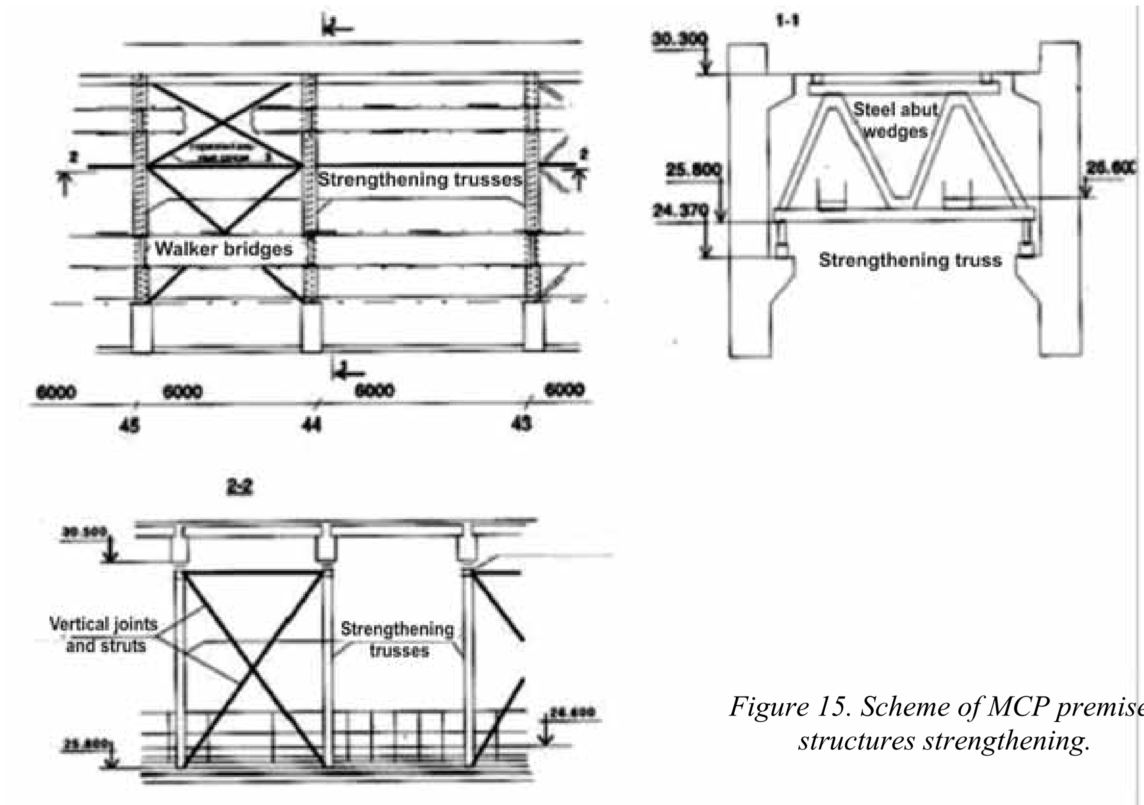

Figure 15. Scheme of MCP premises structures strengthening.

and requires the urgent strengthening. Couplings of ferroconcrete girders with the columns along the row Г and ferroconcrete wall near row E are partially destroyed, the girders are displaced from supporting cantilevers.

The ceiling strengthening was performed by way of erection under the bottom girth of ferroconcrete girders of cribworks made of antiseptized wooden half-sleepers (Fig.16).

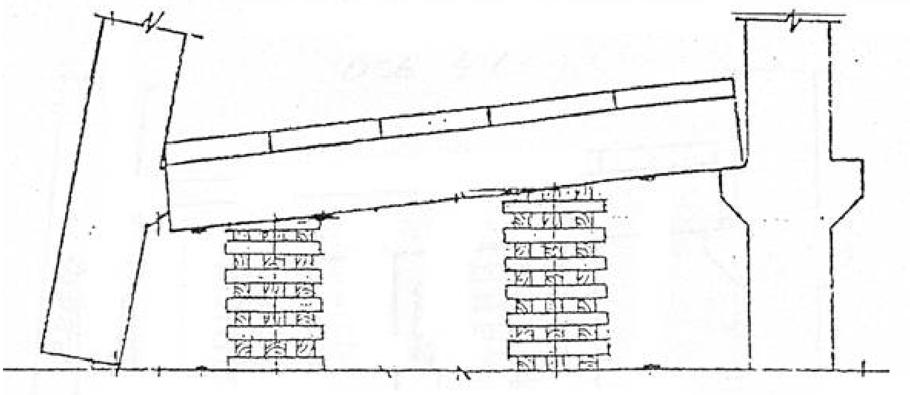

Figure 16. Scheme of strengthening of structures ceilings over premises 805/3.

After the earthquake within the ChNPP area on May 30 and 31, 1990, being of 3,5 - 4 number intensity, the «Shelter» was investigated and "Certification of «Shelter» object conditions investigation" written, which reads that no position changes and notable deterioration of main building structures conditions were fixed.

Research peculiarities of the second stage (1992-1997) concluded as regards:

- extension of research volumes (additionally, supporting structures conditions was assessed of western fragment - ferroconcrete wall along the axis 50 with adjoining framework and walls between the axes 49-51′, supporting joint units of Б1 beams and Б2 on the wall along axis 50, protective-partition wall and coating's metal structures, foundation grounds, adjacent structures of units B and RDAS);

- complex approach (combination of field investigations with probabilistic analysis and computational modeling, with creation of physical models).

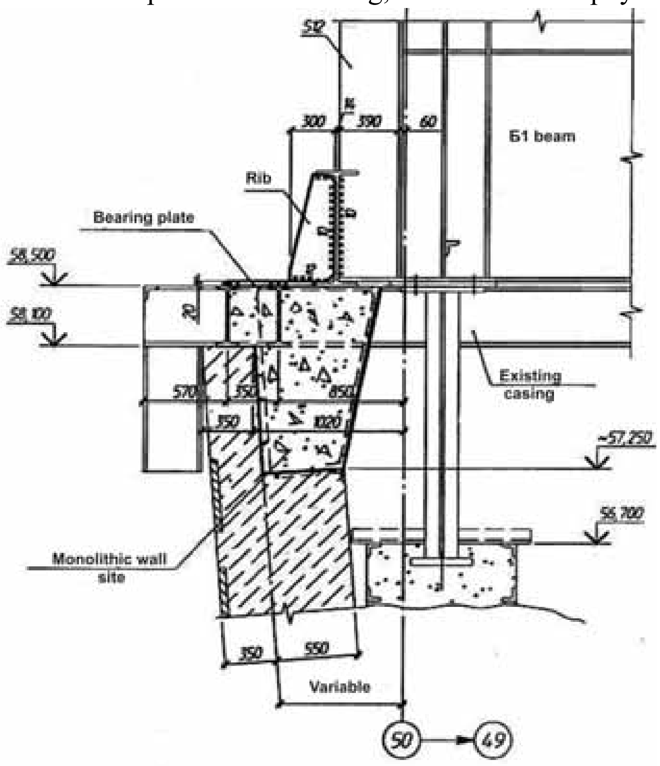

Figure 17. Strengthening of Б1 beams supporting parts and ferroconcrete wall along axis 50 in place of resting upon it of Б1 beams unit (row Ж)

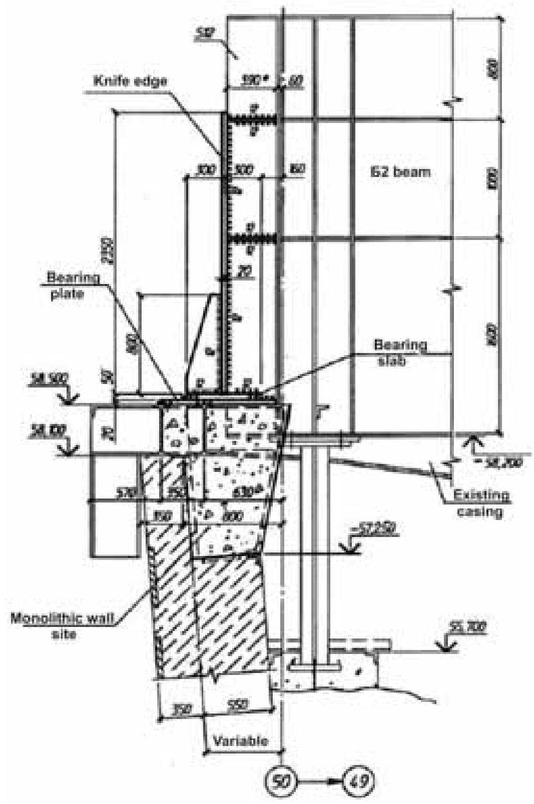

Figure 18. Strengthening of Б2 beams supporting parts and ferroconcrete wall along axis 50 in place of resting upon it of Б2 beams unit (row Ж)

Field investigations have revealed a range of major defects of ferroconcrete wall along the axis 50, which influence essentially not only on bearing capacity and stability of above wall, but also the western fragment as a whole, as well as supporting joint units of Б1 beams and Б2 along the row Ж and П. Shift of wall upper part within the area of abutting of Б1 and Б2 beams units (mark +58.50) in relation to wall bottom part (mark +12.50) makes 500-700 m near row П and around 1000 m near row Ж. Indicated position of bearing wall was considered in erecting the «Shelter», on the site of abutting Б1 and Б2 beams unit along axis 50 row Ж, a need arose in installing a concrete support in non-removable bearing metallic casing. Because of a range of reasons, design decisions for installation of such a support (and simultaneous local wall strengthening) were not fully realized.

Using the results of field investigations, which were made in 1993, actual parameters of indicated metallic casing were defined, conditions of its resting upon structures obstructions and on the wall along the axis 50, as well as the rate of its filling with concrete. The conditions of Б1 and Б2 beams supports unit along the axis 50 row Ж were recognized as unsatisfactory.

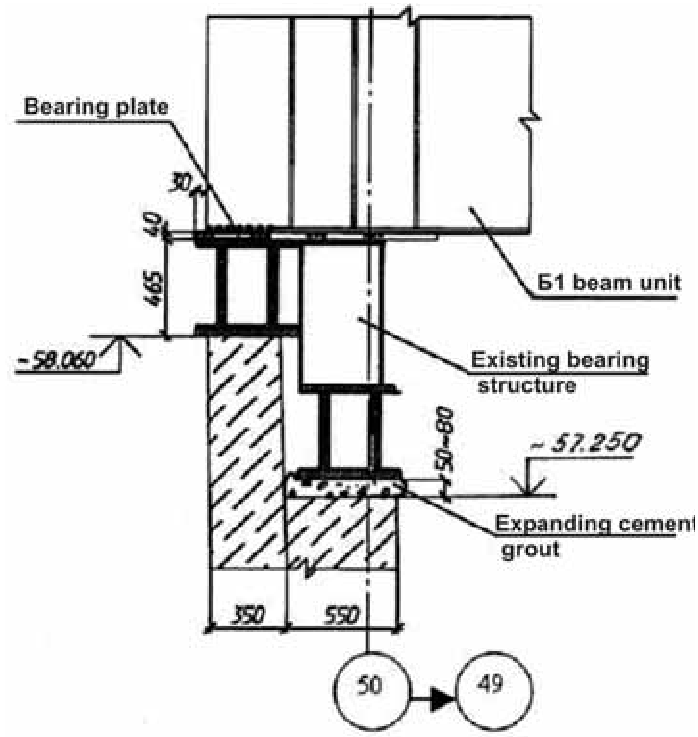

Figure 19. Strengthening of Б1 beams supporting parts and metallic support under Б1 beams in place of Б1 beams unit abutting on ferroconcrete wall along axis 50 (row П)

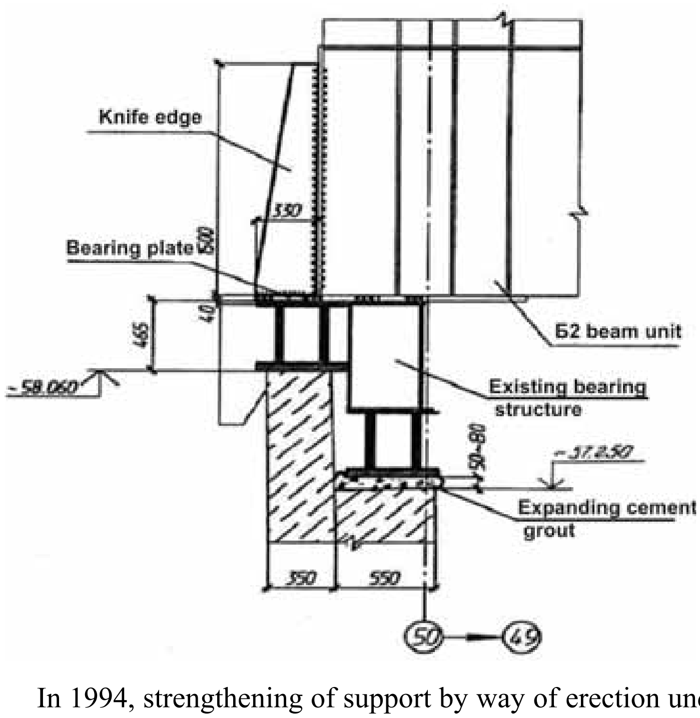

Figure 20. Strengthening of supporting parts Б2 beams and metallic supports under Б2 beams in place of Б2 beams unit abutting on ferroconcrete wall along axis 50 (row П)

In 1994, strengthening of support by way of erection under bottom girths of Б1 and Б2 beams unit of metallic posts abutted on concrete surface inside the casing. However, metallic posts installed in 1994 in conformity with indicated design did not strengthen the support, and were seen as made for the safety, since were installed on concrete body, which together with metallic casing rests upon the preserved ceiling fragment at mark +49.95 through the obstruction of building structures.

At the next third stage (since 1998 till now), researches and works for strengthening «Shelter» main bearing building structures acquired system and large-scale character, and they are performed within the framework of international cooperation.

The works started from the strengthening of ventilation pipe (VP-2) structures. Organizations of Ukraine, USA and Canada were involved in them. Strengthening started late in 1997 and was successfully completed in 1998 summer.

Further works for investigation and stabilization of «Shelter» object structures were continued in conformity with Shelter Implementation Plan (SIP) at the «Shelter» object with direct participation of International Consortium ICC (MK) JV (MORRISON KNUDSEN (USA) – leader, BNFL (UK), Ukrainian organizations NIISK, KIEP and ISTC «Shelter») – Package A tender “Civil engineering” winners.

As an urgent measure of SO building structures stabilization, consortium ICC (MK) JV prepared the draft design of strengthening Б1 and Б2 beams supporting joint units along axis 50, which foreseen the strengthening of both supporting sites of metallic beams and of the sites of wall, on which they lean against (Fig.17-20). The project was realized by Ukrainian building organization «Ukrenergobud» in the year of 1999.

According to results of additional field investigations and refined estimates, consortium ICC (MK) JV substantiated the list comprising 15 stabilization measures, whose realization allows providing structures stability during the time exceeding 15 years, i.e., more, than it is needed for construction and commission of new safe confinement (NSC).

Later this list was reduced to 8 stabilization measures, that is fixed in program decision P2 «Decision for stabilization strategy of roofing, support and structures» of December 24, 2000. This decision is based on changed design criteria in the part of changing designed tornado loading for extreme wind loadings.

During 2002-2003, the consortium KSK comprising Ukrainian organizations KIEP, NIISK and ISTC «Shelter» developed and accorded with regulatory bodies the draft design of stabilization measures. Recently, the works started for its realization.

Developed measures were grouped for the following SO zones.

WESTERN ZONE

Stabilization of “Shelter” object western zone covers the strengthening of western fragment, which includes:

- western buttress wall;
- framework and unit Б walls along the axis 50, 51′ between the rows Д – С;
- Б1, Б2 beams support units along axis 50 rows Ж and П;
- coating between the buttress wall and the wall along axis 50 between the rows Д-С.

Strengthening idea covers the erection of two metallic spatial rod towers with plan sizes being 12×15 m, total height 48 m, with 23-m spatial cantilever span in east direction (Fig.21) to buttress wall west. Indicated towers are installed at mark+14.00 between the rows Е-И and Н-Р in the axes 53-57 on ferroconcrete foundations and connected one to another by spatial systems (trusses) in north- south direction in two levels. The first level corresponds to marks from +26.00 to +32.00; second level – to marks from +44.00 to +50.00. From the eastern side, to spatial truss of second level the brackets are fastened with the step 6 meters that are located in vertical plane, on whose end an abutment of h-beam cross-section is envisaged, adjoining to framework and wall structures along axis 51′. Abutments and brackets are destined for taking horizontal forces in «east-west» direction from the framework and wall

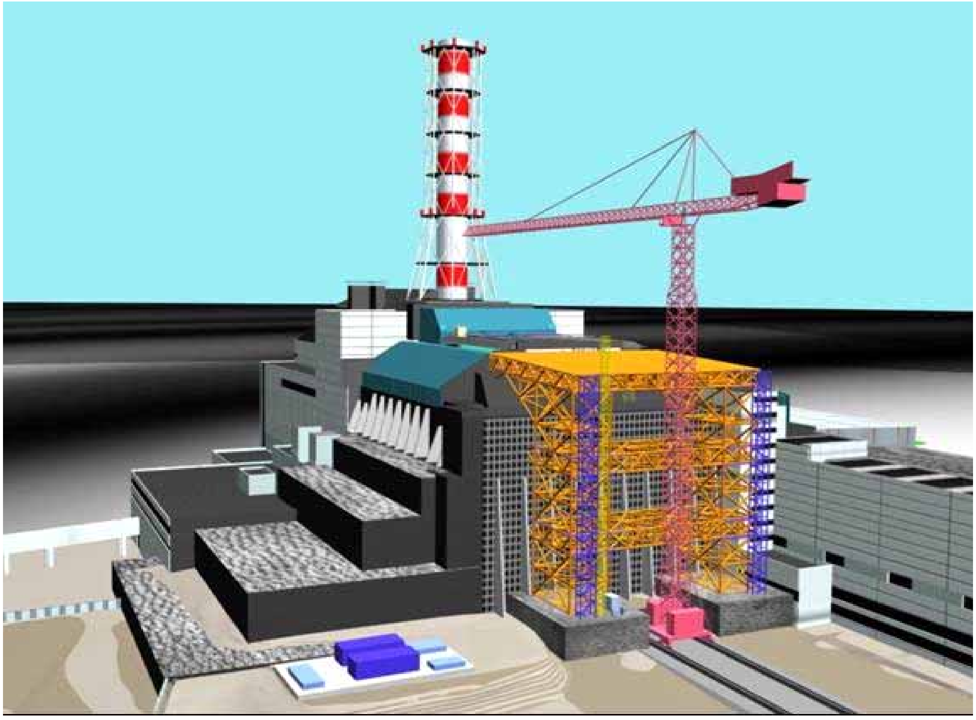

Figure 21. Stabilization measures 2 «Strengthening of western fragment». Scheme of strengthening's metal structures.

along the axis 51′ and therewith prevent the wall displacement in western direction. Towers cantilevers are located in Б1 and Б2 beams units range along the rows Ж and П. At the mark +60.00, on cantilevers ends the welded beams are envisaged, on which by means of special joints at mark +60.55 reconstructed butt-ends of Б1, Б2 beams supporting parts units are abutted. At the mark +56.65, on cantilevers, abutments are envisaged in the wall along the axis 50, which are destined for taking probable horizontal forces from seismic impact in «east-west» direction, thus, strengthening the bearing ferroconcrete wall along the axis 50. Besides, on towers cantilevers the spatial truss is abutted of western fragment coating (spatial system of 3-rd level), to which the upper ends of coating knees (mark +58.525) are fastened.

Ferroconcrete foundations under towers are performed in local zone to buttress wall west between the axes 53-59 and rows Д-К и М-С. Concreting of foundations is tentatively assumed from the mark +0.20 to mark +14.00 – foundations top. Between the axes 54-56, foundations are abutted on foundation plate and bearing unit of buttress wall.

Thus, the works for western fragment stabilization will be performed in local zone, in closed space, between the buttress wall and wall along axis 51′, in upper part of ferroconcrete wall along the axis 50 at the levels from mark +56.40 to mark +58.50 along the row Ж, and at the levels from mark +57.40 to mark +58.50 along the row П, under «Shelter» object coating, as well as on western fragment coating.

SOUTHERN ZONE

Stabilization of deaerating stack framework must be realized by way of strengthening the framework structures of deaerating stack upper tier along the axes 42-50 and rows Б, В. The works will be performed in non-developed premises Г635/3, whose floor level corresponds to mark +24.27.

Strengthening envisages the installation at mark +37.50 (under ceiling girder with mark +38.60) additional horizontal struts fastened to internal blind walls along the rows Б and В and to upper support unit, installed earlier under the girder, as well as the installation at marks +28.40 and +32.90 two more struts (connecting elements), between the inclined knees of additional support.

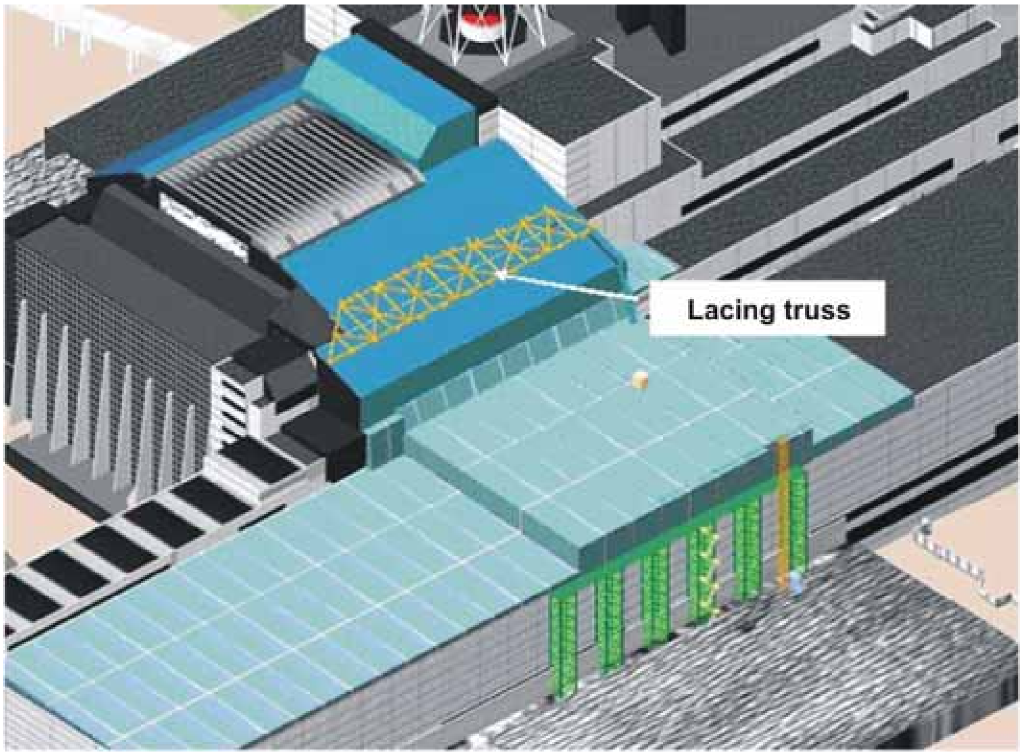

Figure 22. Scheme of location of connection truss on «Shelter» object coating that unites southern «boards-clubs» and southern roofing boards in a rigid disk

Strengthening provides the taking of estimated seismic loadings in "north – south" direction. Connection of «southern boards-clubs» with «southern boards».

Installation of connection elements between 'southern boards – clubs" and "southern boards" is made on outward surface coating, on its southern slope, at the site between the axes 41 and 50 along the row B, i.e. over the place of their resting upon the "Mammoth" beam (Fig.22).

Connection will provide withstanding the extreme wind and seismic loadings.

Stabilization of western support of "Mammoth" beam.

All braces of support's vertical connections are strengthened by way of welding to each brace L-beam of additional L-beam forming "small box" with the existing one.

The strengthening provides the taking of extreme, including seismic loading, in "east – west" direction.

NORTHERN ZONE

Two measures are planned to simultaneously perform here:

- strengthening of northern buttress walls along axis C and its coupling unit with northern clubs;
- uniting of northern boards-clubs with northern buttress wall using anchor-clamps.

Unification of northern boards-clubs with northern buttress wall will be made by way of installation and strengthening of anchors-clamps on supporting cross-arms of boards-clubs. Anchor parts being sealed are placed in partially concreted wall space and made monolithic when filling with the concrete the space of wall upper part, which was not fully concreted during the erection.

The concreting of upper part of northern buttress wall till designed mark provides its bearing capacity.

Installation of anchors-clamps provides the bearing capacity of northern clubs for horizontal loadings, including extreme ones.

EASTERN ZONE

Local stabilization of ventilation shaft walls, which support the Б1 beams.

Stabilization is reached by way welding from bottom part to Б1 beam support plate the two abutments made of L-beams that closely adjoin from the both side to wall lateral surfaces, on which the beam is leaned against. Strengthening provides the durability of Б1 beams abutting zone by way of involvement in work for horizontal loadings of all ventilation vault wall thickness.

The strengthening of "Mammoth" beam eastern support, under which the cavities existing in foundation support from northern and eastern side, must be filled with the concrete. Concreting is assumed to perform in a fixed metallic casing-iron-ring.

The fulfillment of planned scope of building and assembly work (BAW) for building structures stabilization within «Shelter» object conditions is a sufficiently complicated engineering task. First of all, it is related to the problem of safety provision for personnel involved in these works, and maintenance of appropriate and sufficient level of radiation and ecological safety of the Object. To decide that tasks within the framework of stabilization project, a range of documents was developed that substantiate the safety during realization of stabilization measures. The main documents include as regards:

- Report on radiation safety;
- Report on environmental impact assessment;
- RAW management program.

Radiation safety

Development of design decisions and measures providing radiation protection within the "Shelter" object conditions started from analyzing radiation conditions in assumed workplaces and ways of personnel movement.

After completion of conceptual developments for stabilization, complex pre-project researches were conducted. They also included investigation of radiation conditions.

When developing structural and technological decisions, traditional methods and technologies were applied, which are realized in organizing radiation protection at the «Shelter» object. First of all, they include as follows: protection with time and distance, shielding, use of remote technologies, etc. Taken decisions allowed performing the main assembly works using remotely controlled load-lifting crane, and the sites for acceptance of articles and metal structures, prefabricated assembly were removed at maximally possible distance from the «Shelter» object. Besides, the sites will be shielded from the SO by a protective wall, which will provide the personnel protection during assembly works. An important stage for reducing collective effective dose was the choice of optimal access ways for personnel and load delivery. This circumstance has especially essential character during the work in zones with enhanced EDR values, when changeability of a group or brigade in a shift is made several times.

All complex of measures for provision of personnel radiation protection, during SO stabilization work, is divided into following measures groups:

- organizing;
- radiation-hygienic;
- technical.

Within the "Shelter" object conditions, the measures of first two groups are compulsory. Their application is regulated by "Shelter" object documentation, and their realization provides the observance of non-exceeding principle.

The organizing measures include:

- contractor's personnel training;
- organization of work production;
- control and supervision.

Special contractor's personnel training is realized in personnel training centre (PTC) in the town of Slavutich (theoretical training) and at the SO industrial site (practical training). To upgrade the personnel skills for individual technological operations, training ground is created with mock-ups of future workplaces.

Choice of breadboarding units and conditions defining the need in preliminary trainings was made according to the following main indices:

- constrained conditions в planned places for work conduct;
- considerable EDR value at workplace;
- complexity of constructive decision realization;
- opportunity to apply known experience.

When the personnel is trained at mock-ups, the following items are perfected:

- estimate of acceptability of adopted equipment application;
- skills during fulfillment of operations;
- technological process of assembly of strengthening's metal structures;
- time-keeping of all operations;
- recommendations to reduce dose expenses.

To improve the work conduct safety, as well as to check the observance by contractor for erection of design decisions, including the measures for radiation protection, permanent supervision will be provided over the fulfillment of building and assembly works. Especially, one should monitor the accumulation of collective effective dose (CED) during work production. The above will allow comparing the real collective dose to designed values, and, in case of need, to make in proper time the corrective actions.

Radiation-hygienic measures include as follows:

- sanitary-hygienic zoning of work conduct place and sanitary-hygienic classification of works;
- provision of personnel with main and additional individual protection gears (IPG), as well as check of their correct application;
- provision of personnel with appropriate equipment and means of personal and collective hygiene;
- medical services and rehabilitation;
- organization of dosimetric control.

To minimize the prevention radioactive substances transport beyond WPZ boundary, except general requirements to zoning, additional zoning of workplace is envisaged, that is concluded as regards: within the limits of a subzone the sites are defined with different essentially differing levels of radioactive contamination. At the boundary of these sites, transport sanitary locks are located, which provide minimal spread of radioactive substances along «Shelter» object territory. Organization of permanent radiation control in these places was defined in conformity with the ALARA principle.

Choice of individual protection gears (IPG) is made in conformity with requirements of regulatory and operation documentation. Volume and nomenclature of additional IPG application was defined in dependence of activity type:

The factors defining the choice of IPGRO types, include:

- character and quantitative content of radioactive and other harmful substances in air (aerosols disperse content and toxicity, availability of steam phase, harmful substance concentration);
- microclimatic conditions at workplace (temperature, relative air humidity, thermal radiation);
- in-air oxygen content at work conduct site;
- heaviness of work being performed;
- protective and operation properties of individual IPGRO samples.

Additional factors, defining the choice of IPGRO types in specific work conditions for structures stabilization, are as regards:

- work conduct time;
- density of surface contamination with radionuclides;
- EDR value;
- work conduct conditions (works in closed space, constrained conditions).

For substantiated choice of IPGRO types, measurement of labour conditions indices is needed, which includes the both radiation condition indices, and microclimate indices in the WPZ. Special attention will be drawn to measurement of radioactive substance concentrations directly in the breathing zone of workers, since when performing some technological operations that concentrations can, dozens, hundred and, even, thousand fold, exceed their average-shift or average-day values defined with application of stationary samplers.

To protect the personnel from beta-radiation, use of protective eyeglasses, shields and dashboards is planned.

For personnel entry to contamination control area (CCA), sanitary checkpoint for 1430 persons will be used. Personnel passage directly to work performance zones will be made through the stationary sanitary locks in deaerating stack. During work production time, additional temporary sanitary locks are assumed to install in the local zone.

Dosimetric control is an integral part of all radiation safety system during realization of stabilization work. As far as the monitoring of external exposure is concerned, the means existing at «Shelter» object are sufficient and adequate to requirements during realization of stabilization measures. Commission of state-of-the-art system of individual dosimetric control (IDC) will improve the situation, since it also meets the requirements for monitoring of external beta-exposure and neutron (emergency) exposure. The operative control of internal exposure can be improved with installation high-sensitive SHE, which will be placed in premises of new sanitary check point, and daily double (before and after shift) monitoring of personnel exposure, which works in the most contaminated work zones, as well as biophysical personnel monitoring.

Shielding is the most effective method of protection of personnel staying in work production zones. Shielding of work production zones and access ways to them will be set up as permanent or temporary.

Permanent shielding represents the boards-shields manufactured of protective materials and placed in special metallic framework. The boards can be installed on existing structures or on new metal strengthening structures (MSS). They are installed during the preparative work and, without absolute need, are not subject to subsequent dismantling.

Under temporary shielding, specially created sliding protective buildings of box type (PB), shielded attached and sliding sites, is implied. Their manufacture is assumed to make at a plant located outside the exclusion zone. Depending on box location places, they are destined for personnel stay during forced technological breakdowns, control and survey over work process, putting on and off additional IPG, etc.

Except temporary and permanent shielding of work production zone, local shielding of radiation sources can be used – first of all, radwaste clusters close to workplaces. This shielding method can be applied in case of detection (e.g., during obstructions clearing) of intensive radiation sources, and their removal from work zones is embarrassed by different circumstances (e.g., source is located under a concrete layer).

In conformity with ALARA principle, the decisions being developed for shielding were optimized. That process included the reduction of collective effective dose (CED) for personnel, as well as optimization of shielding facility installation thickness and choice of their installation place.

Most important factor for shielding optimization is the data on gamma-radiation angular distributions at workplaces. Optimization was made in the following sequence:

- analysis of results of angular distributions measurements of gamma - radiation intensiveness close to workplace;
- definition of direction to main sources forming EDR in measurement places;
- gamma-radiation sources are identified for measurement places;
- forecast of probable location of sources defining EDR at workplace with considering the distance to sources, possibility to shield workplace from the source by «Shelter» object structures;
- estimate of relative contribution into EDR from identified sources;
- estimate of contribution into EDR of radiation from six main directions, which can be shielded.

When shielding the access ways, as the main parameter defining expediency of shielding, intensity factor of using defined route sites is accepted. Considering large labor expenses for displacement and installation of shields, in the routes inside the «Shelter» object, where is impossible to hoist the shields with load-lifting mechanisms, a conclusion was made on inexpediency of manual shielding of access ways.

When choosing a material for shielding, analysis was made of main characteristics of different materials applicable for gamma – radiation attenuation: lead, steel, concrete, tungsten and depleted uranium.

The analysis has shown, that for work inside the «Shelter» object, the lead is the most preferable material. Use of expensive materials with big atomic number gives no principal advantages, but only increases the design costs.

A quantitative characteristic of efficiency of shielding measures application is preventable CED. According to estimate data, the preventable collective dose of personnel, due to shielding, made **more 35 Sv.**

During stabilization works, a need will arise of involvement of large amount of people (to 150 men per a shift) and machinery. On top of that, simultaneously will be performed large scopes of work in different places, both inside the object, and on industrial site territory. Such a work organization requires an effective management of personnel and of industrial processes. The use of video survey will allow reducing the exposure dose for «Shelter» object personnel and for contractor organizations due to control of observance of installed routes, allowed work time, as well as preliminary familiarization of contractor personnel with the place and character of work conduct. Using video survey system, permanent presence of work leader in place of their conduct is not required in conditions of unfavorable radiation situation.

Estimate of expediency of dust suppression works was based on comparative analysis of positive and negative factors of measure realization.

As positive factors, the following items are considered:

- prevention of dust production during the works and movement of personnel, reduction of probability of additional internal exposure;
- exclusion of probability to transport the dust arisen during personnel movement behind the boundaries of working site and its precipitation on the personnel, which is not linked with the conduct of stabilization measures;
- minimization of environmental influence.

To negative factors additional material expenses, labor- and dose expenses for dust suppression realization can be referred.

When arranging the WPZ and access ways, decontamination is inexpedient, if it will provide reduction of external exposure dose. For instance, the removal of detected sources of intensive gamma-radiation can essentially improve the work production conditions. Such sources can be detected when clearing the WPZ territory, removal of concrete inflows, etc. In considering the expediency of decontamination of WPZ surfaces, e.g. cutting-off of apertures along buttress wall height, decontamination is recognized as inexpedient one. Exclusion makes the decontamination of internal and external surfaces of protecting boxes.

Welding and fire works during realization of stabilization measures are performed outside the structures fencing «Shelter» object or in premises having considerable sizes (e.g., breakdowns of premises 2001/4, 2007/3 et al.). Radioactive aerosols being produced are to be removed. That is why an actual becomes organization of safe removal of discharged air, since this flow can lead to radioactive aerosols resuspension, which will entail considerable increase of radioactive substance concentrations not only in the WPZ, but also in adjoining premises and territory. The above, first of all, is related to the works in internal premises, where the place of probable air release can be distant from WPZ more than at 50 m.

Use of local fan is taken as inexpedient only in individual places.

Assessment of environmental impact

The "Shelter" object being an ecologically hazardous facility represents an enhanced treat associated, in first turn, with the penetration of radioactive substance into environment. Despite the fact that currently the radioactive releases from the SO are lower than established reference levels, hazard exists of their considerable intensification as a result of realization of measures for SO structures stabilization. When drafting the project, impacts were assessed to aerial, water mediums, as well as on topsoil, social and technogenic media.

Based on building decisions, release values were estimated in conducting different stabilization works. Results of estimates of radioactive substance releases for each measurement are shown in Fig. 23.

Impacts onto aerial environment.

Because of the fact that radioactive release sources are located at different height over earth level, that essentially influences the spread and transport of radioactive substances in aerial environment, release sources grouping was made on this attribute and summary release was calculated. It allowed obtaining maximally probable volumetric contamination at any distance from the SO.

Thus, release sources from earth level are forming a release being of $8{,}12 \cdot 10^{6}$ Bq, from sources located at SO roofing level, the release will make around $1{,}88 \cdot 10^{9}$ Bq, and release from ventilation pipe (VP-2) will make around $3{,}2 \cdot 10^{8}$ Bq.

In Table 7, maximally probable volumetric air contaminations at 10-km and 30-km distance are shown, $ДК_А$ and $ДК_в$, as well as comparisons of concentrations with admissible.

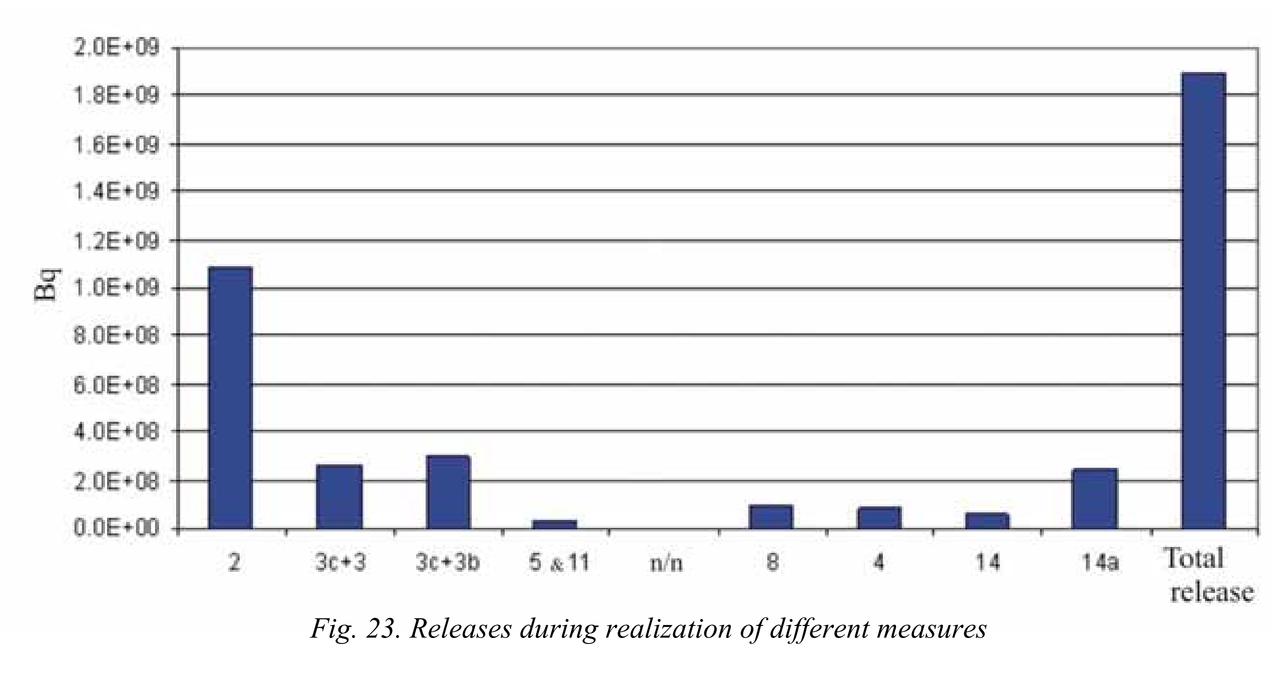

Fig. 23. Releases during realization of different measures

Table 7

Nuclides	Admissible concentrations, Bq/m3		Concentrations under normal operation, Bq/m3		Relation to ДКа	Relation to ДКв
	ДКа	ДКв	10 km	30 km	10 km	30 km
^{137}Cs	60	0.8	0.009	0.003	0.0002	0.004
^{90}Sr	10	0.2	0.008	0.002	0.0008	0.01
Alpha-emitting transuranic isotopes	0.03	0.0004	0.00055	0.00016	0.018	0.40

As Table 7 demonstrates, in normal conditions of work realization, impacts to aerial environment will be considerably less than admissible levels.

Impact to soil.

The main way of radioactive substance coming onto topsoil is natural precipitation on soil surface of radionuclides from radioactive release in the air, which are produced during the SO stabilization.

Estimates have shown, that the operation, which exerts the most impact to soil medium at small distances from the SO - territory planning in local zone, and at a more distance from the SO - average release during realization of all stabilization measures.

Table 8 shows maximally probable surface contaminations at 10-km distance, as well as their comparison with the RL.

Table 8

Nuclides	Reference levels, Bq/m^2	Surface contaminations under normal conditions at distance 10 km, Bq/m^2	Relation to RL
^{137}Cs		3.1	
^{90}Sr		2.8	
Beta sum	33300	6.0	0.0002
Alpha-emitting transuranic elements	333	0.2	0.0006

The data demonstrated in Table 8 give the reason to conclude that under normal conditions of work conduct for stabilization, the impacts to soil will not exceed the RL.

Impact to water medium.

Due to small values of radioactive releases to air under normal conditions of work conduct, even total penetration of this activity into water medium will not notably reflect at value of its contamination (activity release from exclusion zone by river Prypyat makes around $5 \cdot 10^{12}$ Bq/year).

Impact ways to water medium under an accident - radionuclides precipitation from air release, as well as, washout from soil surface.

A conclusion is made, that under normal conditions of work conduct, and under an accident, no supernormative impact to water medium will occur.

Effective dose.

Under normal conditions of work conduct, the dose obtained in the maximum of near-surface concentration, makes around 4 mkSv.

In case of an accident with maximal aftermath, effective dose at 10-km distance will make around 4 mSv, and under a condition, that a man will stay during the accident from lee side from the SO and will not use any IPG. At 30-km distance (at the boundary of exclusion zone), effective dose will make around 1 mSv.

Impact to plant and animal world, reserved objects.

As a result of stabilization activities, the most probable impact to plant and animal world will be radionuclides penetration into adjoining ecosystems of neighbouring territories in aerosols composition. On top of that, summary average daily activity amount under a release, which is produced by SO stabilization measures, is essentially less of reference average daily levels of radionuclides releases through VP-2. Based on above, a conclusion is made, that radiation constituent will no exert any influence to natural topsoil of adjoining territories and faunal complexes.

Impacts to social environment.

A large scope of works, which is planned to realize during SO structures stabilization, stipulates the involvement of considerable amount of additional personnel, that can exert indirect positive impact to conditions of social environment of the town of Slavutich – satellite town of ChNPP.

Closure of hail growth enterprise, which for Slavutich is ChNPP, increased essentially the probability of deterioration of social status of majority of town inhabitants. Emotional stress provoked by the above exerts a negative impact to psychological condition of public that produces general deterioration of vital activity conditions. Origination of new opportunities for job placement, due to planned SO works will serve to strengthening of confidence in the future and will enhance public well-being.

Guaranteed provision of employment for a part of public when performing the work at the SO, will serve as a factor, contributing to improvement of social environment conditions of Slavutich and for a part of public of other Ukraine's regions.

Analysis of probable impacts to exclusion zone personnel and public, which dwells behind its limits has shown, that a solely probable impact type is radiation factor. Estimates of additional dose loading to personnel and public are conditioned by trouble-free work conduct for SO stabilization, testify a negligibly small size of impacts.

Impact to technogenic medium.

At the territory adjoining to SO, acting facilities of housing and communal services and socio-cultural assignment are absent, as well as monuments of architecture, history and culture guarded by the State. In zones of probable impacts, recreational zones and cultivated landscapes are absent.

Stabilization activity does not assume any change of existing conditions of operation of enterprises located (or planned) at ChNPP industrial site and behind its limits (SNFR-2, ПКО SRW et al.). That is why, a solely factor of impacts is the increase of dose loading to personnel of these enterprises. Carried out analysis has shown, that dose loading increase under normal work conduct (maximally 0,0042 mSv) will be negligible.

Performed assessment of environmental impact allowed developing adequate protective measures. The main measures include as regards:

- survey over radionuclides penetration into environment during the work conduct for SO stabilization (radiation monitoring);
- radioecological monitoring of personnel working in ChNPP close and far zones.

Radiation monitoring of natural media, during conduct of SO stabilization measures, must provide obtaining of reliable data on current radiation conditions of components of medium undergoing the impacts. Currently, existing routing monitoring net covering the major part of exclusion zone territory satisfactorily provides representative radioecological monitoring of current conditions of environmental components. It is a sufficient one and there is no need in its expansion and inserting of additional items into existing regulation.

Thus, realization of stabilization measures will increase «Shelter» object radiation safety, and during the conduct of building and assembly works, human and environmental radiation protection will be provided.

9. NSC conceptual design

Creation of New safe confinement (NSC), as a part of activity for «Shelter» object (SO) conversion into an ecologically safe system is regulated by ratified by Ukraine of international laws [1-5], laws of Ukraine [6-13], regulatory-legislative acts [14-21] and other documents.

The funds for design are granted by European Bank for Reconstruction and Development (EBRD) on behalf of donor countries.

Conceptual design (Feasibility report) of New safe confinement (CD (NSC FR) was developed by order of State Specialized Enterprise Chernobyl Nuclear Power Plant (SSE ChNPP, town of Chornobyl) by Consortium (comprising: Bechtel International Systems (USA); Electricite' de France (France); and Battelle Memorial Institute (USA)), which performed the works with participation of Ukrainian consortium KSK (comprising: Research and Development Institute for building structures (NIISK, city of Kyiv); Kyiv Research and Development and design-constructor Institute «Energoproekt» (KIEP, city of Kyiv); Interdisciplinary Scientific-Technical Centre «Shelter» (ISTC «Shelter», town of Chornobyl)).

Creation NSC is one of the main stages of conversion of «Shelter» object, representing a treat for environment, into an ecologically safe system.

In conformity with Provisions of Law of Ukraine «Of general fundamentals of further operation and decommission of Chernobyl NPP and conversion of destroyed power Unit 4 of this NPP into an ecologically safe system», NSC creation must provide the achievement of the following goals:

- provision of protection of personnel, public and environment from influence of nuclear and radiation hazard sources associated with the SO existence;
- provision of conditions for realization of activity aimed at SO conversion into an ecologically safe system, including for dismantle/strengthening of unstable SO structures, FCM removal and RAW

Figure 24. General view of NSC

management.

Based on above goals of NSC creation, its functions are defined as follows:

• Restriction of radiation influence to public, personnel and environment by established limits under NSC normal operation, violation of normal operation, emergency situations and accidents, including the accidents during the dismantle of unstable structures, and future handling of FCM and RAW;

• Restriction of spread of ionizing radiation and radioactive substances located in the SO under normal operation, violations of normal operation, emergency situations and accidents. The conduct of this function is provided by:

- integrity of NSC fencing structures during a long-term operation period;
- prevention of SO unstable structures collapse, by means of their dismantle or strengthening for a period defined by conditions of NSC safe operation;
- restriction of penetration of rain (storm) and from melted snow water;
- protection of groundwater from contamination with radioactive substances, located in SC.

A general view of NSC is shown in Figure 24. In architectural design, the NSC will present a complex of buildings, which comprise:

• new fencing structural casing;

• internal premises for placement of NSC system equipment, control boards, doghouses and sites for primary treatment of dismantled radioactively contaminated elements;

• auxiliary buildings (sewer-pumping station, building of fire-extinguishing facility, et al.).

Conceptual design envisages the creation, within the framework of NSC design, of the following elements:

• Load-lifting mechanisms to provide the works for NSC operation and SO conversion into an ecologically safe system;

• Systems providing the NSC operation.

New fencing structural casing will represent a metallic structure of arched type with gables. Arched structure will cover the «Shelter» object, a part of Unit B, southern and western pioneer walls, as well as a part of currently existing SO local zone. Eastern gable will abut to existing structures of Plant,

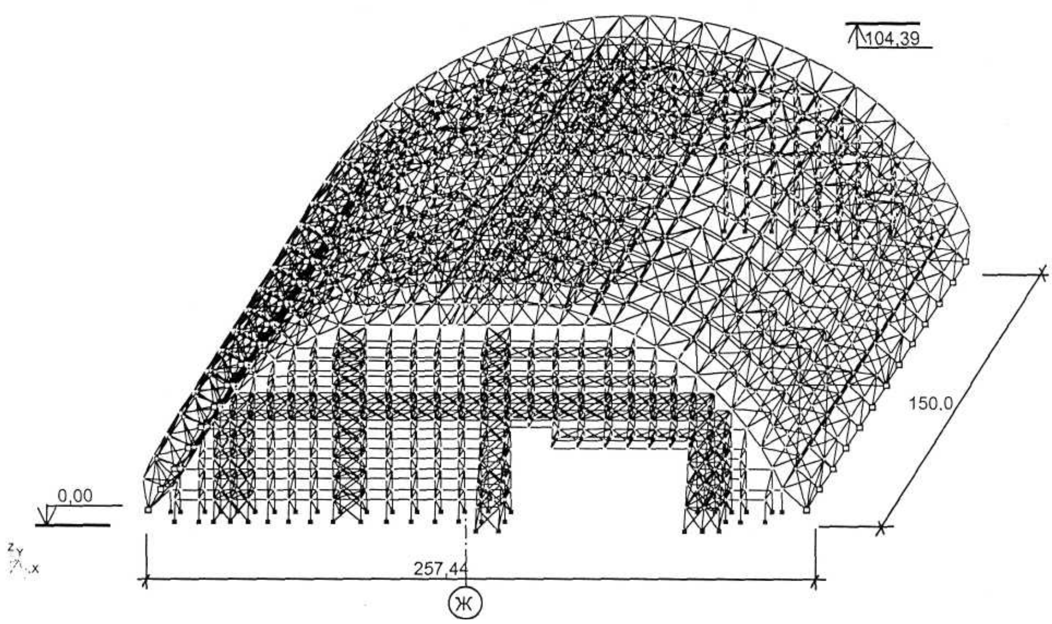

Figure 25. General view of bearing structures of NSC casing.

western one will lean upon own foundation. Turbine hall will partially come forward through western wall.

General view of bearing structures of NSC casing is shown in Fig.25. Geometrical sizes of casing make: span - 257,44 m, width - 150 m, height - 108,39 m, thickness -12 m.

In conformity with selected decisions, arched structure consists of bearing and fencing elements:

- Main bearing elements are circular contour arches comprising a range of internal and external arches connected one to another by truss lattice (arched type trusses);
- Fencing structures consist of two decks - outward deck (roofing) and internal (ceiling) deck, which are attached to horizontal purlins fastened to arched truss girths.

Arched structure consists of 13 flat arches. Span between the flat arches makes 12,5 m.

NSC envisages the following systems providing NSC operation:

- Dust suppression system;
- NSC fire systems;
- Ventilation systems;
- Water supply systems;
- Sewer systems;
- Heat supply and conditioning systems;
- Decontaminating solution supply system;
- Compressed air supply system;
- Power supply and electrical safety system;
- Integrated NSC management system;
- Communication and industrial television system;
- Physical protection system;
- Liquid and solid RAW management system.

Main parameters influencing the period of NSC building structures operation are as regards:

- Radiation factors impact;
- Corrosion factors impact.

In conformity with CD (FR) NSC, designed NSC operation term makes 100 years. Indicated term is reached due to:

- consideration during design of extreme loadings and impacts in conformity with acting regulatory documents;
- application of materials with enhanced corroding resistance;
- choice of optimal operation mode;
- structural decisions providing maintainability.

NSC structure envisages a probability of subsequent change of roofing and wall panels in operation period, which does not demand NSC partial opening. Change of panels will be made using shielded platforms of technical maintenance hanged on rails inside and outside of NSC arch main elements.

Within the framework of CD (FR) NSC, strength estimates were made of NSC fencing structural casing and foundations with considering the following external impacts associated with natural phenomenon: seismic impacts; wind loadings; snow loadings; tornado loadings; air temperature changes; lightning impact; precipitations.

In estimating, for seismic impacts the following values were taken:

- Designed earthquake (one time per 100 years)- 5 numbers according to MSK-64 scale
- Maximal estimated earthquake (one time per 10 000 years) - 6 numbers according to MSK-64 scale.

For wind loading, the following values were used (in accord with SNiP 2.01.07-85 and PiNAE-5.6):

- Normative value of wind pressure - 0,3 kPa (30 kgc/m^2);
- Estimated loading - 0,42 kPa (42 kgc/m^2),
- Extreme loading -0,75 kPa (75 kgc/m^2);
- Reliability coefficient for loading-1,4 and 2,5 correspondingly for estimated and extreme loading.

For snow loadings, the following values were used (according to SNiP 2.01.07-85 and PiN AE-5.6, as well as with considering historical climatological data based on repetition rate, one time per 10 000 years):

- Normative value of snow cover weight - 0,7 kPa (70 kgc/m^2);
- Estimated loading -1,0 kPa (100 kgc/m^2);
- Extreme loading - 2,1 kPa (210 kgc/m^2);
- Reliability coefficients for loading - 1,4 and 2,0 correspondingly for estimated and extreme loading.

For tornado loadings, estimate is made in conformity with «Main regulatory requirements and estimated characteristics of tornadoes for Chernobyl NPP site», introduced by Order No 64 of Ukraine's Derzhbud of 21.10.2002.

In conformity with NP 306.1.02/1.034-2000, probability of realization of initial event, bringing to a need of public resettlement in case of exceeding estimated tornado class for newly designed objects of nuclear power engineering should be established equal to $P=1\cdot10^{-6}$ 1/year, and for facilities under construction, operation and reconstruction - $P=1\cdot10^{-5}$ – 1/year. Estimated characteristics of tornado with indicated probability for ChNPP site are shown in Table 9:

Table 9

Estimated tornado characteristics	For tornado with probability $1\cdot10^{-5}$	For tornado with probability $1\cdot10^{-6}$
Estimated class of probable tornado	1.5	3.0
Exceeding probability, (event/year)	$1\cdot10^{-5}$	$1\cdot10^{-6}$
Maximal velocity of funnel rotation, (m/s)	50	81
Velocity of tornado forward movement, (m/s)	12.6	20.3
Pressure difference between funnel centre and periphery, (gPa)	31.0	81
Length of tornado propagation path, (km)	5.0	28.6
Width of tornado propagation path, (km)	0.05	0.29

For air temperature characteristics, the following values were used (according to SNiP 2.01.07-85):

• Normative temperature value:	Minimum	-20°C;
	Maximum	+26°C;
• Estimated temperature value:	Minimum	-22°C;
	Maximum	+29°C;
• Reliability coefficient for loading		1,1;
• Extreme temperature values (one time per 10 000 years)	Minimum	-43°C;
	Maximum	+45°C.

Lightning impacts are expected at the level, under which is enough to have lightning-protection system meeting the requirements of PUE and «Instruction for arrangement of lightning-protection for buildings and structures (RD 34-21-122-87).

For maximal precipitation amount, the following values were used:

- On average over 20-minute period - 31 mm;
- Extremely over 20-minute period (one time per 10 000 years) - 72 mm;
- Extremely during a day (one time per 10 000 years) -190 mm.

Strength estimates confirmed that realization of proposed constructive decisions would provide the NSC stability under all considered external impacts associated with natural phenomena. Particularly, stability of NSC main supporting structures and foundations under a class 3.0 tornado is confirmed, and absence of a need, under such initial event, of public evacuation in conformity with criteria of NRBU-97, NRBU-97/D-2000 and NP 306.1.02/1.034-2000.

When developing CD (FR) NSC, the following external technogenic impacts were considered:

- explosion;
- aircraft collapse;
- fire;
- initial events associated with existing ChNPP facilities.

Analysis of impact to NSC structures from explosion sources at the ChNPP site and behind its limits has shown that under such initial events the loadings will be less of expectable by a tornado.

Aircraft collapse was excluded from consideration as a designed base due to following reasons:

- In conformity with the national requirements of acting in Ukraine regulatory-legislative documents, such initial event is not seen for the facilities for RAW and FCM management, to which the SO is referred, and, correspondingly, the NSC;

- B ChNPP zone, organizing-technical measures accorded with appropriate bodies are envisaged, which prevent aircraft flights;
- Based on estimates performed in designing other ChNPP objects, probability of such initial event evaluated at the level of $1 \cdot 10^{-6}$/year. Existing estimates of probability of aircraft collapse on a specified object for western-European countries, where aerial traffic is more intensive, than in Ukraine, makes $<10^{-7}$/year. In conformity with criteria, established in NRBU-97, such a rare initiating event can be not considered.
- Use of this event as a design basis would lead to considerable unjustified increase in cost and making more complicated the NSC structures.

In CD (FR) NSC, aircraft collapse is seen as “out-of-design” event.

Analysis performed at pre-project development stage has shown, that additional impacts influencing NSC design decisions are absent under external fires.

Analysis of initial events associated with existing ChNPP objects has shown, that ventilation pipe VP-2 collapse on the NSC would lead to destruction of bearing structures of casement, and a probability of such event is above, than it is admitted by acting regulations. In this connection, in CD (FR) NSC a conclusion is made on a need to dismantle ventilation pipe before the start of NSC pushing into designed position.

Emergency situations at other ChNPP objects (LRTP, ПKOSRW, SNFR-1, SNFR-2) will not provoke any additional loading on the NSC.

Main decisions for NSC erection technologies

Within the framework of CD (FR) NSC, main decisions were developed for such aspects of erection organization as regards: preparation of building territory, infrastructure for provision of construction, possible erection technology is drafted.

Territory preparation works include clearing of building site, works for arrangement of engineering mains at building site, works for planning territory at building site, organization of auxiliary objects for construction.

Proposed in CD (FR) NSC infrastructure for provision of NSC construction must enable delivery of tube and ferroconcrete structures, as well as of building materials, such as concrete, sand, fixturing, armature, etc. Besides, infrastructure must provide power supply, water supply, heat supply, sewer (storm and household), and removal of producible RAW and construction waste.

In CD (FR) NSC, comparative analysis of construction technologies options is made. As a result it was stated, that most preferable option is manufacture of section elements of arched structures at Ukraine's plants, their assembly beyond the site limits with subsequent delivery to assembly site.

Manufacture behind the site limits has a whole range of advantages, since plant-manufactures are equipped with all appropriate infrastructures and possess opportunities to provide required quality control, and considerable part of works will be performed beyond the limits of zone with high radiation fields. On top of that, the amount of equipment, workforce and scope of work, performed at building site, will be minimized.

Assembly of arched structure starts after installation of pushing ways, assembly site and installation of supporting units and bearing beds under the first supportable section. Structure will be assembled of individual 12.5-m wide sections. On top of that, two methods of arched structure assembly are seen.

The first method includes the assembly of arched structure sections using crane with load-lifting capacity 1600 t and two cranes of less load-lifting capacity.

The second method is based on the point that assembly of arched structure sections is made with using winch-hoisters. The both methods are real and technically realized, on top of that, the second one permitting to perform more quantity of assembly works on earth level, that increases their safety and productivity, is considered in CD (FR) NSC as a more preferable.

Pushing of arched structure (Fig.26) is made after installation of pushing ways, foundations under arched structure, foundations of eastern and western gables, as well as completion of assembly of pushing equipment and ventilation pipe dismantle. Most preferable pushing method and, according to CD (FR) NSC estimate results, is the pushing with applying tractive effort. This pushing method provides the required friction coefficient and is more floppy due to possibility to change the amount of ropes and towing jacks at each stage of arched structure pushing.

Figure 26. Modeling of arched structure's pushing process to «Shelter» object.

After the arch is pushed in design position, completion of gables arrangement is made and sealing of arched structure. Connection of engineering mains and arched structure equipment can be started after pushing completion and assembly of equipment inside the NSC.

Management of RAW producible during NSC erection

Proposed in CD (FR) NSC decisions for RAW management under NSC construction are based on the following positions:

- For management of RAW producible during construction – existing at ChNPP RAW management scheme will be maximally used;
- In defining the decisions for management of RAW producible during construction - main decisions и planned measures, developed within the framework of integrated program of ChNPP RAW management are considered;
- In defining the decisions for control and inventory of nuclear materials and RAW during construction – it is adopted that this activity will be realized within the framework of system existing at the SO;
- Under NSC construction, only the RAW are subject to removal, which are located in building work zones, for the rest RAW located in technogenic layer of local zone and SO industrial site must be provided possibility of their delayed removal during operation or dismantle of NSC.

During the NSC erection, the main RAW volumes will be produced by:

- removal/displacement of on-land objects covered by construction zone (building structures and their fragments, mains, construction waste, etc.) and cleaning of areas from shrubs etc.;
- earthwork (crushed stone, ground, sand, concrete fragments, etc.);
- drilling works (cores containing the above fractions).

SRW, producible under the NSC construction, according to contamination type will be presented as both surface contaminated materials (large-sized fragments structures and buildings being dismantled), and volumetrically contaminated (small-sized fragments and loose waste). Main contamination of indicated materials is expected by radionuclides of ^{137}Cs, ^{90}Sr, $^{239+240}$Pu, $^{\text{and }238\text{Pu}}$, ^{241}Am, which will determine gamma-radiation EDR, surface and volumetric contamination rate.

As volumetrically contaminated SRW the high-level waste (HLW) are expected, which can be presented as fragments of negligible sizes (active core fragments and strongly contaminated concrete fragments). The rest SRW will be referred to low- and intermediate-level waste (LIL SRW), of predominantly 1 category low-level waste).

During works for removal/displacement of existing mains, removal around 1300 m^3 of ground is expected, which received radioactive contamination as a result of 1986 year accident, in which can include the impurities that due to contamination level are referred to SRW 3 category. Performed in CD (FR) NSC estimate of volumes of technogenic layer demanding removal have demonstrated that during creation of NSC foundations, up to 82500 m^3 ground can be excavated. It is assumed that the volume of SRW 3 category (HLW) during earthwork would make around 120 m^3.

When preparing internal sites under arched structure, additional ground can be excavated in volumes of 24170 m^3 (for the most, with contamination at background level values).

General scheme of radioactively contaminated ground management includes two level of their sorting:

- primary sorting according to ground removal place with the purpose:
    - primary identification and HLW segregation using the criterion «EDR of extractable ground»;
    - dividing the rest waste into small-sized and large-sized;

- detailed ground sorting at a specially arranged site with the purpose to divide into the waste subject to burial and, the waste that can be used for backfilling during erection of foundations.

The grounds having high contamination level will be forwarded to interim monitoring point for certification, and from that place they will be transferred for long-term storage/burial:

- to PLRW «Buryakivka»,
- to industrial complex for handling solid radioactive waste (ICSRW) - after its commission.

Large-sized LIL SRW meeting the burial acceptance criteria, after surfaces dust strengthening can be transported directly to PLRW « Buryakivka » or to ICSRW.

To provide the fulfillment of above works, the sites for waste removal and management envisage the following equipment and facilities:

- specially equipped machinery with attached equipment for handling radioactively contaminated materials;
- specially equipped site for ground segregation into categories;
- check points with dosimetric control;
- stations for decontamination of RAW management machinery and equipment.

In order to reduce radioactive substance concentrations in the atmosphere in work production places, use of dust suppression is envisaged.

Nuclear safety provision

Under normal conditions of NSC construction, to provide nuclear safety of CD (FR) NSC is envisaged:

- not to worsen the conditions of atmospheric precipitation discharge from existing SO roofing;
- not to create additional apertures in SO roofing, as well as other ways for incoming atmospheric precipitation in premises, where nuclear hazardous FCM clusters are localized;
- not to worsen conditions in part of condensation moisture production as compared to existing conditions;
- not to realize technical decisions, which could change existing water flows system inside the SO and contribute to moisture accumulating in nuclear hazardous zones;
- not to worsen the conditions for functioning of current system for collection and removal of SO radioactively contaminated water;
- exclude the use of technological waters when performing work at the sites adjoining to SO nuclear hazardous zones ;
- exclude conditions violating efficiency of existing system for nuclear safety monitoring:
    - information-measuring system (IMS) «Finish-P»;
    - FCM monitoring systems (MS FCM) «Signal»;
- to go on maintaining FCM in subcritical condition in volume established by acting SO technological regulation, using the existing systems:
    - system for supply of nitric gadolinium solution;
    - facility for operative insertion of neutron-absorbing solution;
    - dust suppression systems (in mode of neutron-absorbing solution supply).
- to realize organizing measures for nuclear safety provision in conformity with acting SO technological regulation.

During NSC construction, to reduce SCR generation risk in emergency situations occurred as a result of SO building structures collapse, CD (FR) NSC envisages as follows:

- Measures for stabilization of SO building structures will be performed before NSC construction start, that will result in reducing collapse risks to acceptable level;

- NSC structures will be designed in conformity with criteria и requirements of nuclear and radiation safety;
- Considerable part of building and assembly works will be performed at safe distance from the SO, which excludes direct mechanical impact to it;
- Building and assembly works in close vicinity from the SO, including NSC pushing, will be realized with applying technologies and technical means с high reliability indices;
- For fire extinguishing in nuclear hazardous zones is assumed using of water-free compositions and/or aqueous compositions with neutron-absorbing additives;

As a whole, during NSC construction (in normal conditions and in emergency situations) with considering envisaged measures, nuclear safety will be provided at the level existing for operated SO. When the NSC will be commissioned, SO nuclear safety level will be essentially improved.

Radiation safety provision

Availability of radioactive materials in the SO defines potential radiation hazard of all activity for SO conversion into an ecologically safe system, including activity in NSC design scope. In CD (FR) NSC, measures for provision of radiation safety were prepared with considering the fact that NSC construction and operation will be realized as activity with open ionizing radiation sources.

During NSC design realization, radiation conditions will be defined by:

- availability of radioactive substance in work production zones;
- radiation background created by SO;
- radioactive aerosols release from SO;
- direct activity (dust rise, RAW management, including FCM).

To provide radiation safety, CD (FR) NSC envisages at all stages of NSC design realization:

- organizing measures;
- technical measures;
- sanitary-hygienic measures.

Organizing measures, which are common for all stages of NSC design realization, include:

- personnel training;
- planning of work; organization of safe work production;
- control and supervision.

As designed reference levels of individual exposure of personnel and radiation conditions for all the stages NSC design realization, CD (FR) NSC takes the values established currently at the SO.

During NSC construction, the main technical measures providing radiation safety will include as regards:

- protection with distance;
- shielding;
- dust suppression.

Protection with distance implies minimization of works being performed close to SO, especially on high marks, for the above the CD (FR) NSC envisages the following decisions:

- Part of labor-intensive work will be carried out beyond exclusion zone limits;
- Assemblage of NSC building structures and a range of its technological system will be realized at a far distance from SO (150 m);
- Structures assembly procedure envisages their assemblage on earth level.

Shielding of work production zones will be provided by application of:

- protective boxes;
- relocatable shields;

- shielded attached or traveling platforms;
- shielding of operator cabins for technical means.

Measures for short-term dust suppression (damping with water) will be carried out under probable increase of dust rise in work zone during work production, or personnel movement. Long-term dust suppression (laying of localizing compositions) will be carried out in case of need to localize radioactive contamination (dust-strengthening) on surfaces of transportable large-sized structures and other elements without containerization.

Dosimetric control during construction includes as regards:

- monitoring of radiation conditions, which provides:
  - EDR monitoring;
  - monitoring of contamination levels by radioactive substances of work surfaces of premises, equipment and vehicles;
  - monitoring of volumetric activity of radioactive substance in work zone air;
  - radiation control at all RAW management stages;
- individual dosimetric control (IDC) of personnel including:
  - IDC of external exposure due to beta- and gamma-radiation with application of individual dosimeters;
  - IDC of internal exposure, which is made on the basis of data of direct and indirect biophysical measurements;
- system of operative and long-term planning, inventory and storage of data on individual personnel exposure doses.

Collective effective dose of personnel during NSC construction, preliminary evaluated in CD (FR) NSC with considering realization of indicated measures, made - 450 men-Sievert. It is assumed that realization of organizing and technical measures according to ALARA principle can reduce this value to -250 men -Sievert. The above estimate is subject to more precise definition at the stage of detailed design during preparation of Work Production Project (WPP).

Assessment of impacts to components surrounding natural environment

During the works over CD NSC design, estimates of impacts of activity under design to surrounding natural environment were made.

Impacts to aerial medium

As a result of performed estimates, for emergency situation scenarios under consideration the following impact levels were established:

- value of radioactive releases penetrating into atmosphere, under condition of SO collapse without NSC, makes around $1{,}59 \cdot 10^{13}$ Bq;
- value of radioactive substance releases, under condition of SO collapse inside NSC, will make from $8{,}49 \cdot 10^{10}$ to $8{,}08 \cdot 10^{11}$ Bq depending on SC ventilation conditions (from 0,1 to 1 SC volume a day).

Impacts to soils

Under normal conditions of NSC design realization, impact to soils from SO aerosol releases precipitation till construction completion will be preserved at existing level, negligible as compared to radioactive contamination occurred in the first months after 1986 year accident.

After NSC commission, release amount will reduce.

Under emergency situations, the most soil contamination is predicted in case of base option (SO collapse without NSC) and first option (SO collapse during NSC pushing), under extraordinary meteorological condition (atmosphere stability category on Pasquill F, wind velocity - 1 m/s). On top of that, maximal (along plume central axis), surface contamination values at 10-km distance (additionally to existing contamination) will make from 5% to 60% of existing contamination of ChNPP exclusion zone soils at given distance.

At the boundary of ChNPP exclusion zone, maximal (along plume central axis), additional surface contamination will make from 30% to 100% of existing contamination of soils at the boundary of ChNPP exclusion zone.

Beyond ChNPP EZ limits, at 50-km distance, maximal (along plume central axis) additional surface contamination will make:

- with radionuclide ^{137}Cs - 3,2 $10^4 Bq/m^2$;
- with radionuclide ^{90}Sr- 2,8 $10^4 Bq/m^2$;
- with radionuclides $^{238+239/40}Pu$ - 6,5 $10^2 Bq/m^2$,

that will exceed existing levels in several times.

For SO collapse inside NSC option, maximal soil contamination under analogous meteorological conditions is forecast in dozen-hundred times less (depending on NSC ventilation mode) as compared to contaminations under SO collapse without NSC.

Maximal summary (for all radionuclides) additional surface contamination at 10-km distance is forecast at level of 1,7 10^4 Bq/m^2 that makes not more 2% of existing contamination of ChNPP EZ soils at given distance.

At the exclusion zone boundary, maximal summary surface contamination is forecast at level $3{,}3 \cdot 10^3$ Bq/m^2 that makes not more 10% of existing contamination.

Impacts to water medium

Under normal conditions of NSC design realization, impact to surface water from SO aerosol releases precipitation before the completion of construction will be preserved at existing negligible level. After NSC commission, SO releases amount will reduce.

Under emergency situations, impact to surface water will be defined by direct atmospheric precipitation on water surface of river Prypyat, as well as precipitation on its flood plain close to NSC with subsequent radionuclides outflow from drainage areas. Forecast of emergency contaminations of surface waters performed in the EIAR covers Kyiv, Kaniv, Kremenchuh and Kakhovka reservoirs. The largest aftermath are forecast in SO without NSC collapse and SO collapse during NSC pushing.

The biggest peak of ^{90}Sr concentrations in water is forecast for 41 day after the accident, and for both options of emergency situation will make:

- for Kyiv reservoir (Kyiv SPP) - 684 Bq/m3;
- for Kaniv reservoir - 389 Bq/m3;
- for Kremenchuh reservoir - 225 Bq/m3;
- for Kakhovka reservoir - 178 Bq/m3.

The maximal value of presented above (for Kyiv reservoir) makes 34% of admissible ^{90}Sr concentrations in drinking water.

The maximal ^{137}Cs concentration under basic and first options in Kyiv reservoir makes 455 Bq/m3, in Kaniv reservoir - 137 Bq/m3 (correspondingly 32% and 11% of admissible ^{137}Cs concentration in drinking water). Maximal concentration of Pu, ^{23} Pu and ^{41}At forecast for Kyiv reservoir, does not exceed 1 Bq/m3 for each radionuclide.

For SO collapse under NSC option, level of radionuclides income depends on NSC ventilation conditions. Under ventilation equal to 1 NSC volume a day, maximal increase of ^{90}Sr and ^{137}Cs concentrations as compared to background level makes 25% and 91% correspondingly (11% and 2% of admissible concentrations for drinking water). Under ventilation equal to 0,1 SC volume a day, ^{90}Sr and Cs concentrations will be an order less, and annual concentrations will be only at 0,3% exceed the background values of indicated radionuclides content in Kyiv reservoir water.

Simulation of impacts to underground water is made in the EIAR with considering the fact that the main contamination source is water infiltration from SO premises 001/3. On top of that, radionuclides transporting by underground waters was considered independently of current contamination of underground waters conditioned by other sources (surface contamination, burial sites near the SO, etc.).

For ^{90}Sr possessing the biggest migration capacity, the following results were obtained:

- Under scenario of SO collapse without NSC, concentration in underground waters, exceeding $4\cdot10^9$ Bq/m3, will be observed at less 100-meters distance, $1\cdot10^2$ Bq/m3 level will be provided yet at 600-m distance from the SO. Contamination field will reach river Prypyat after 800 years, on top of that, ^{90}Sr concentration, because of radioactive decay, will drop at $5{,}7\cdot10^{-9}$ fold of initial values.
- by SO collapse under NSC, ^{90}Sr concentration in underground waters will be reduced, practically, to zero.

Assessments of impacts to geological medium and climate, which were described in the EIAR at conceptual level, has shown the absence of some significant impacts to these medium components.

In connection with existing high contamination level of ChNPP EZ territory, a conclusion is made in EIAR on the fact that impact to flora, fauna and reserved objects within the limits of this territory will be weakly distinguished even under base option of emergency situation (SO collapse without NSC). On top of that, extremely restricted atmospheric transport and availability of background contamination of flora and fauna makes negligible emergency impacts behind the ChNPP EZ limits.

Estimate of mutual impacts of NSC and objects of surrounding technogenic medium

As a result of performed impacts analysis, it was defined as regards:

- impacts of emergency situations at LRTP, ICSRW, SNFR-1, SNFR-2 will not entail any additional loading to the NSC;
- unfavourable impact of collapse of existing ventilation pipe of power Unit 4 is ruled out, since it (pipe) is being dismantled. Newly erected pipe will be designed for extreme impacts. On top of that, in conformity with NSC construction schedule, existing ventilation pipe must be dismantled before starting NSC pushing works.

Under normal conditions of NSC design realization, its impact to surrounding technogenic medium will be expressed in displacement of existing life support systems of the SO and ChNPP Unit 3 (electricity supply networks, systems of water supply and household sludge sewer, etc.) located at NSC construction site.

Assessment of impacts to social environment

Realization of NSC design will positively impact to social environment in several fields:

- it will essentially reduce the risks of public exposure under emergency situations at the SO;
- it will reduce psychological tension in society associated with SO collapse treat;
- it will provide employment for part able-bodied public of towns of Slavutich, Chernihiv and other settlements;
- it will provide loading of Ukraine’s industrial enterprises during manufacture of NSC structures and components.

Measures for minimization of environmental impacts

NSC creation, in itself, is a measure aimed at minimization of SO environmental impacts, since NSC availability will allow:

- isolate RAW located in SO;
- reduce probability of nuclear incidents due to exclusion of atmospheric moisture penetration on FCM clusters inside SO;
- perform works for handling FCM and RAW under protective casing.

Minimization of negative environmental impacts during NSC construction will be achieved by means of realization of following technical and organizing measures:

- dust suppression in earthwork production places;
- dust strengthening;
- decontamination of applicable mechanisms and vehicles;
- application of technologies with minimal dust rise;
- organization and control over RAW transporting and management.

Minimization of negative environmental impacts during NSC operation in the course of dismantling unstable SO structures will be reached by means of realization of the following technical and organizing measures:

- Arrangement of ventilation system, with using aerosol filters for exhaust air cleaning;
- Zoning of NSC territory and premises;
- Dust suppression in work production places;
- Organization of radiation control system;
- Decontamination of vehicles leaving the NSC limits;
- Use of revetment of premises, where radioactive substance release into premises is possible;
- Organization of building structures control system;
- Restriction and control of NSC discharges and releases.

Estimate of potential exposure

In CD (FR) NSC, analysis was made of potential exposure of personnel and public as a result of realization of activity associated with NSC construction and operation, and substantiation of non-exceeding of exposure risk criteria defined in NRBU-97/D-2000 was made.

Estimate of potential exposure during NSC construction

In CD (FR) NSC, the following emergency situations during NSC construction are seen, which can lead to potential exposure of public and personnel:

- SO fire due to error of personnel/failure of equipment during NSC construction before pushing NSC arch;
- SO collapse due to error personnel/failure of equipment during NSC construction before pushing NSC arch;
- SO collapse due to extreme wind during NSC construction before pushing NSC arch.

Fire at the SO due to error of personnel/failure of equipment during NSC construction before pushing NSC arch can occur as a result of the following initial events:

- ignition of materials during the welding;
- ignition of electrical equipment;
- vehicle accident in local zone.

When assessing potential exposure under a fire at the SO, the following assumption and initial data were applied:

- It is assumed that as a result of fire no SO collapse occurs;
- Total release during origination of fire at the SO makes $4{,}8 \cdot 10^{10}$Bq;
- Fire duration makes 4 hours;

As a result of estimates it was stated that individual effective dose under a fire for non-protected personnel close to SO makes around 12,6 mSv.

At a distance from SO under given initial event, maximal individual dose is formed at around 10-km distance and makes - $7 \cdot 10^{-3}$ mSv. Thus, release influence under a SO fire to personnel located at far distance from the SO, will be negligible.

Dose of public at the ChNPP EZ boundary makes $4\text{-}10^{-3}$ mSv.

Collapse of SO building structures, due to error of personnel/failure of equipment during NSC construction before pushing NSC arch, can occur because of collapse of assembly crane or load on the SO.

In conformity with existing models, volume of SO aerodynamic shadow was estimated - around 106 m3. Thus, conservatively assuming that all activity precipitates in aerodynamic shadow zone, radioactive substances concentration in air makes around $7{,}79 \cdot 10^{6}$ Bq/m3. Cloud existence time is taken as equal to time, during which the wind will pass distance equal to aerodynamic shadow length. Under wind velocity of 3.3 m/s, this time is equal to 45 s. Over this time, individual effective dose for non-protected personnel, close to the SO, makes -58 mSv.

At a more far distance from the SO, maximal individual dose is formed at 1-km distance and makes around 4 mSv. Thus, inhalation dose for personnel located at a bigger distance from the SO will be significantly less, than the above dose close to the SO. Dose for public at the ChNPP EZ boundary makes 0,1 mSv.

Estimates of potential exposure during NSC operation

To estimate potential exposure during NSC operation, the following emergency situations under NSC operation are seen, which can lead to potential exposure of public and personnel:

- SO fire under essential reduction of fire protection due to personnel error under NSC operation;
- SO collapse due to earthquake with loss of power supply during SO structures dismantle and NSC operation;
- impossibility to close NSC transport gate due to error of personnel/failure of equipment during SO collapse.

Potential exposure in case of realization of indicated emergency situations is associated with inhalation intake of radioactive aerosols into organism. The source of aerosols origination is a fire or SO collapse. Since these critical events occur after NSC arch is pushed on its place, therefore, producible aerosols are scattered inside the NSC. Eventually, a part of aerosol materials comes into environment, the remained materials precipitate inside the NSC. Reduction of radioactive substance release is provided due to shut off of arched space ventilation. It is evident, that maximal individual dose of potential exposure for personnel staying inside the NSC is essentially higher, than for the personnel being outside the NSC.

Fire at SO under and essential reduction of fire protection due to personnel error during NSC operation can occur as a result of the following initial events:

- ignition of materials in the course of welding;
- ignition of electrical equipment;
- vehicle accident inside the NSC.

In estimating potential exposure by an SO fire, the following assumption and initial data are used:

- It is assumed that as a result of fire, no break of NSC structures integrity will occur;
- Total release during SO fire origination inside the NSC makes $4.8 \cdot 10^{10}$ Bq [2].
- Fire duration makes 4 hours;

Maximal individual dose of potential exposure will be received by personnel located inside the NSC due to radioactive aerosols inhalation, on top of that, inhalation time makes 1 hour (it is assumed that the fire was detected and the personnel was evacuated through 1 hour after origination of strong fire, that is a sufficiently conservative assumption).

Results of estimate have shown that over the time needed for evacuation, maximal individual dose of potential exposure for non-protected personnel inside the NSC makes around 11,3 mSv. Considering the fact that the personnel in NSC will work in IPGRO, or in isolated premises, real dose is forecast at least at order less – 1,1 mSv.

Release from the NSC will make $2 \cdot 10^{8}$ Bq.

Maximal individual dose outside the NSC makes around $4 \cdot 10^{-4}$mSv. Evidently, that inhalation dose of potential exposure of personnel inside the NSC is essentially less of dose inside the NSC.

Dose of public at the boundary of ChNPP EZ makes $3 \cdot 10^{-8}$ mSv.

Under SO collapse due to earthquake with loss of power supply during SO structures dismantle and NSC operation, the estimates made have shown as regards. During loss of power supply, failure of NSC control systems can occur, which will entail the event when ventilation system shutters can remain in open position. The above brings to increase of air exchange with surrounding environment to 200% NSC volume per a day and relevant accelerated drop of radioactive aerosols concentrations inside the NSC.

When estimating potential exposure dose, the following assumptions and initial data are used:

- Under earthquake, no NSC structures destruction will occur;
- Total release under collapse of SO structures building inside the NSC makes $7.79\text{-}10^{12}$ Bq:

Maximal individual dose of potential exposure will be received by the personnel located inside the NSC due to radioactive aerosols inhalation; on top of that, inhalation time makes 20 min (maximal time needed for emergency evacuation of worker);

Over the time needed for evacuation, maximal individual dose of potential exposure of personnel inside the NSC makes 44 mSv. Under an essentially more probable particular collapse, the dose makes around 15 mSv.

Release beyond the NSC limits will make $8{,}4 \cdot 10^{9}$ Bq. Maximal individual dose of personnel outside the NSC will make around 3 mSv (under partial collapse - around 1 mSv). Evidently, that inhalation dose of potential exposure outside the NSC is much more less than the dose inside NSC.

Dose for public at the ChNPP EZ boundary makes around 10 mSv.

Conclusion

Choice of all principle technical decisions for NSC is confirmed by estimated substantiations performed within the framework of CD (FR) NSC. Particularly, estimated substantiation are made for different options:

- mode of NSC thermal isolation and ventilation;
- arched structure configuration;
- structural decisions on foundations, et al.

For NSC structure being proposed in CD (FR) NSC, strength estimated substantiations are carried out, which confirm NSC stability under extreme values of different loadings and their combinations. Particularly, stability of supporting structures and NSC foundations is confirmed under a class 3.0 tornado.

In CD (FR) NSC, assessment of environmental impacts during NSC design realization is made. It is shown that under normal realization of design and in emergency situations, “Shelter” object’s environmental impacts have essentially smaller aftermath, if the NSC is available, as compared to absence of fencing casing.

In CD (FR) NSC, potential exposure of personnel and public as a result of realization of activity associated with NSC erection and operation is evaluated, and non-exceeding of exposure risk criteria is substantiated, which is defined in NRBU-97/D-2000.

As a whole, in CD (FR) NSC at conceptual level, probability of achievement of set objectives in NSC creation is demonstrated, which are as follows:

- providing protection of personnel, public and environment from the influence of sources of nuclear and radiation hazard associated with the SO existence;

• providing conditions for realization of activity aimed at SO conversion into an ecologically safe system, including that for dismantling/strengthening unstable SO structures, FCM extraction and RAW management.

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Analysis of the Version "Earthquake is the Cause of the Chernobyl Accident"

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For the first time an earthquake as a possible cause of the accident at the 4th unit of Chernobyl NPP was discussed in 1996, after publication of an article by Vitali Pravdivtsev "Chernobyl: 10 years after" in December issue of "*Technika – molodezhi"* magazine. It was argued in the article that the reactor was destroyed by an explosion after the earthquake which occurred under the nuclear power plant at 01:39 AM 26 April 1986. The article attracted attention of nuclear physicists at Kurchatov Institute of Atomic Energy (KIAE), and with assistance of geophysicists they promptly checked the information provided in the article. A clear mismatching of the time of the described event and the moment of the beginning of breakdown process at the NPP forced them to systematically reveal and count all mistakes and discrepancies of Vitali Pravdivtsev's article (there were more than 80 of them). That's why the result of comparison of the drawing from the article (by which the author supported his sensational conclusions) with the original of seismograms, presented by geophysicists participating in the investigation, was not surprising. They stated that "an illustration (that was the word they used for Pravdivtsev's seismogram – *N.K.)...* is a hand-made drawing of the imaginary event that allegedly occurred at 1:39! [1]". Pravdivtsev, the author of the article, did not dare to argue with experts' conclusions.

In 1997 a group of scientists from the United Institute of the Physics of Earth (RAS, Moscow, Russia) Institute of Geophysics of NAS of Ukraine, Institute of Geography of NAS of Ukraine revisited this theme. Although their conclusions were formulated in a more prudent manner, they preserved a less-stringent approach to the selection of facts that they needed to prove their point. For example, it is stated in the paper that the seismic event occurred (with one second precision!) at 01:23 39±1 s. At the same time, an inaccuracy of the distance to the epicenter of the seismic event is ± 10 km, which immediately adds to the error of the moment of seismic event ± 3.4 s (10 km divided by velocity of surface waves V=2.9 km/s gives 3.4 s). Besides, the paper did not indicate the moment of receiving seismic signal at registration points, i.e. at seismic stations, and distance which the signal traveled from the point of origin – all this makes verification of authors' conclusions difficult.

A little later (in 2000) the same group of authors wrote on Chernobyl accident again [3]: *"Weak earthquake (MPУ = 2.6, MS = 1.4) was recorded by three seismic stations in the area of Chernobyl NPP... Preliminary analysis of the seismograms tells of the natural origin of the shake..."*
An accuracy of the distance to epicenter was specified by the authors once as ± 10 km [2], then as ± 15 km [3]. Although this fact leads to the increase in uncertainty of the moment of event to (1± 5.3) s, it is not taken into account.

Further on in the papers an appearance of a "low frequency extensional clatter and strong vibration of units" is described, with indication of the precise time (allegedly documented by the NPP personnel) when this event started. This is not true. Yes, there was vibration and clatter during 6-8 seconds, as witnesses stated. But there was no registration of these events as commencing at precisely 1:23:39 (there is no proof for this in these papers). Even with one-minute precision no one at Chernobyl NPP noticed the commencement of "clatter and vibrations", because explosions that followed brought totally new tasks (evidences provided by witnesses give time between 1:15 to 1:25, and records of personnel which participated in the programme – 1:24-1:25).

One more point. Authors consider only two hypotheses on the nature of the event which was registered by seismic stations: earthquake and explosion. Thus they have overlooked a third version, namely that seismic stations might have recorded, for example, the following sequence of events:

- most powerful clatter and hydroblows which accompanied local increase of power generation in the lower part of right half of the reactor; during this period control systems recorded drop of flow rate through all eight main circulation pumps [5];
- several explosions – one of them lasting, resembling a double explosion, and in 2-3 s a very strong third explosion (quotation from explanations by personnel).

Thus, even from preliminary analysis of papers [2, 3] it is possible to conclude that authors were willing to relate the accident at unit 4 of Chernobyl NPP with a hypothetical earthquake.

Let's quote from the abovementioned papers some excerpts, which served as a basis for authors' conclusions:

"An analysis conducted at KSE OIEPh RAS shows that in the night of 25-26 April 1986 (25 April at 21:23' Greenwich time) all three stations recorded a relatively weak seismic event. Surface waves could be seen on all channels of three stations...

For estimates of the time of event and coordinates of epicenter of seismic source... velocity of surface waves with the period about one second was used (2.9 km/s)...

Results of the analysis of seismic records show that the examined event took place at 01:23:39 (± 1s) local time (here and further on local time is used for chronology of the events at Chernobyl NPP)...

The time of the seismic event recorded by the KSE OIEPh RAS stations coincide with the accuracy to first seconds with the low frequency extensional clatter from the direction of water intake station at the cooling pond and strong vibration of units (01: 23: 38)...

In accordance with estimates which could be found in different reports, the explosion at unit 4 of Chernobyl NPP occurred during the time interval from 01: 23: 49: to 01: 23:59. Thus it is possible to assume that the event in question did occur at least 10 s before the explosion at ChNPP, but more likely 16 s before...

It was estimated that the epicenter lay about 10 km to the East of ChNPP. Low amplitudes at seismograms and the fact that stations were located at one side from epicenter would not allow for better accuracy of epicenter location than ±10 km. Thus it could not be ruled out that the epicenter of the event may coincide with the location of the NPP.

It is not possible with the available data to make estimates of the depth of the source...

Dynamic characteristics of the seismograms differ from recordings of the surface explosions and resemble forms of the registered local earthquakes which were obtained during seismic monitoring of Chernobyl NPP in 1995-1996...

Direct comparison of the form of the Chernobyl event record and records of explosions at local quarries at similar distances was also made.

Finding out the tectonic nature of the seismic event is based on data of detailed seismic description of the territory of Chernobyl NPP... Additional investigation provided evidence that... the highest number of micro-earthquakes is observed... at a distance 10-15 km to the East of ChNPP... Thus, the most likely center of the local earthquake of the night of 25-26 April could be the junction of Teterev and South-Pripiat deep faults, located 10-15 km to the East of ChNPP site...

Envelope line of maximum seismic intensity... may lead to the estimate of earthquake intensity of 7.25. These estimates, of course, are made for epicenter of the earthquake.

Note that due to resonance effects in buildings accelerations could be several times higher. Hence it could not be ruled out that the system of reactor, unprotected against vibrations, would suffer from seismic impact during testing, and this would lead to disruption of technological processes and eventually to an explosion of the reactor.
Evaluated... intensity of seismic shakes at ChNPP industrial site in these cases would be equal approximately 2...
In case of epicenter location at the depth up to 1 km, from formula... we obtain the magnitude 5-6...
Conclusions. *So, the obtained data indicate that the considered seismic event with... epicenter near ChNPP occurred, most likely, 16 s before the explosion at the power plant; its beginning approximately match the time of low-frequency sound and vibrational effects, noticed by power plant operators; spectral- time characteristics of this event significantly differ from records of the quarry explosions with epicenters at the same distances.*
Hence it is possible to conclude that there is a high likelihood that the system of reactor 4 of Chernobyl NPP, unprotected against vibrations, suffered from a seismic impact combined with resonance effects, and that made insertion of the graphite absorption rods impossible, a sharp increase of reaction was not prevented and this resulted in intensive generation of gases and their explosion."

Let's consider two hypotheses on the nature of the recorded event. According to the first one, the recorded signals are a consequence of one or two explosions at the ChNPP, which occurred due to an accident at unit 4. According to the second hypothesis, an earthquake occurred in the area of ChNPP. Let's look how the real fact can match these hypotheses.

Comparison of the events at ChNPP 26 April 1986, which was presented in official materials of the Governmental Commission of the USSR on the investigation of the causes of the accident at ChNPP, including the well-known report, prepared by USSR for IAEA experts [Abagian et al., 1986], as well as in reports by Institute of Nuclear Researches of Academy of Science of Ukrainian SSR, *NIKIET* and reports by the Complex expedition of the Institute of Nuclear Energy (INE), demonstrates the following:

- The moment of the beginning of the seismic event, registered by seismic stations, within seconds coincides with the low-frequency clatter from the side of water-intake station at the cooling pond and strong vibration of units, noticed by power plant operators (1:23:38).
- At 01:23'40" the unit shift supervisor ordered pressing button EPS-5, which commands insertion of absorption rods in the core. The rods moved downward, but in several seconds shocks were heard and operator saw that the rods stopped before they reached lower limit stop switches.
- At 01:23:48 technological control devices recorded grows of pressure in the reactor and in steam separator drums.
- Not later then 01:23:49 the centralized monitoring system "*SKALA*" switched itself off.

According to estimates made in different reports, the first explosion at unit 4 of ChNPP occurred during interval from 1:23:49 to 1:23:59. If one uses only records of the NPP personnel and readings of the NPP control system, then some impact on the NPP did take place between 21 and 11 sec before the explosion. Results of the analysis of seismograms show that seismic source also appeared 11 seconds before the control system failed to function. According to the record in operating log, at 01:39 one more explosion occurred, but for some reason it was not recorded by the seismic stations.

On the basis of these facts reports conclude: "*It is not possible to rule out the possibility, that the system of reactor 4 of Chernobyl NPP, while it was operating in upset conditions, suffered a seismic impact and this led to impossibility of insertion of graphite absorbing rods with all implied consequences"*.

Is this conclusion trustworthy? To answer this question, let's consider in more detail information presented in papers [2, 3]. If the facts are presented in a table, we will have a compact and easy to analysis form of the material.

Table 1. Data from papers on seismic event near ChNPP (26.04.86).

1. Seismic event occurred at 1:23:38±1
2. Moment of registration of event at the sites of seismic stations – NOT CITED
2. The depth of the source of seismic event - NOT DEFINED.
3. Distance from seismic stations to epicenter of the event - NOT CITED
4. Accuracy of distance to epicenter - ±10 km, ±15 km
5. Most likely location of epicenter - 10-15 km to the East of ChNPP.
6. Intensity of seismic shakes on industrial site of ChNPP – 2.
7. Oscillation which was registered best – SURFACE WAVES.
8. Velocity of propagation of surface waves - 2.9 km/s
9. Explosion at unit 4 occurred during interval from 1:23:49 to 1:23:59.

Table 2 Conclusions of the papers on seismic event in the area of ChNPP (26.04.86).

1. «Some impact on NPP did occur during the period 21-11 s before the explosion».
2. «Seismic stations recorded not explosion or several explosions, but an EARTHQUAKE».
3. «So, the obtained data indicate that the considered seismic event with... epicenter near ChNPP occurred... 16 s before the first explosion at the power plant»
4. «Envelope line of maximum seismic intensity... may lead to the estimate of earthquake intensity of 7.25. These estimates, of course, are made for epicenter of the earthquake".
5. «Hence it is possible to conclude that there is a high likelihood that during the period of testing the system of reactor 4 of Chernobyl NPP, unprotected against vibrations, suffered from a seismic impact and that, combined with resonance effects, made impossible an insertion of the graphite(?) absorption rods to stop reaction runaway, and this resulted in intensive generation of gases and their explosion.»
6. «According to the record in operating log, at 01:39 one more explosion occurred, which was not recorded by the seismic stations.».

Comparing the information in Table 1 and Table 2, one can notice obvious mismatch between the initial data and conclusions made on the basis of these data.

Let's consider this phenomenon in more detail. **To begin with, lets try and find an answer to the question – are earthquakes of 6 points and more possible in the area of ChNPP?**

The following is the answer to this question provided by the Research and Design Institute of Building Elements of the State Committee of Civil Engineering of the USSR (*НИИ строительных конструкций Госстроя СССР*) in 1995 [4]: *«Analyzing the map of general seismic zone classification OCP-87, presented by the Institute of Earth Physics of the Academy of Science of USSR, as well as information on earthquakes of 1230 and 1510 on the territory of Kyiv oblast... the area of the ChNPP is indeed located on the border of 5 and 6 point seismic zones...*

An earthquake of 1230, according to the data of S.V.Evseev..., for Kiev region also could be ranged as 6-point (S.V.Evseev writes "6-?") according to the description in Lavrentijevsky Chronicle... a collapse of the stone church (if it was not decrepit or poorly built, and the data were not exaggerated) corresponds, in *accordance with the scale of intensity of earthquakes MSK-84 to the intensity about 7 points (more than 6). However, this single fact (even if it indeed occurred) is not sufficient for ranging this zone as 7-point, because subsequent (well documented remote earthquakes of the Vranch zone (ZONA VRANCHA) earthquakes of 1790, 1802, 1940, 1977… according N.V.Shebalin's data did not exceed 5 points on MSK-84 scale for Kiev and its vicinities».*

One more question – what was the assumed seismic impact which main buildings of the ChNPP had to withstand? This is an answer provided in 1995 by the institute "Atomenergoproekt" (the question, and hence the answer, were relevant for both 3rd and 4th units of ChNPP [5]: *«The "Norms of designing nuclear power plants with reactors of different types" (PiNAE-5.6), enacted in 1.01.87, require that buildings and constructions of NPP of the 1st category in terms of their radiation and nuclear safety, should be designed taking into account particular impacts, including seismic impacts: Design impact (DI) and Maximum design impact (MDI). The former and the letter are defined for Chernobyl NPP as follows: DI – 5 points, MDI – 6 points.*

…In accordance with categorization of PiNAE-5.6, constructions of the main building: main compartment (units A, B and BCPO) and deaerator construction were assigned 1st category.

Taking this into account, the Moscow Branch of "Atomenergoproekt" Institute in 1987 accomplished theoretical and experimental investigations of earthquake resistance of constructions (equipment) of buildings belonging to categories I and II for Kursk, Smolensk and Chernobyl NPPs.

Results of these investigations are presented in the report "Measures to provide for seismic resistance of nuclear power plants with reactors RBMK"...

Calculations that were carried out demonstrated that load bearing capacity of constructions of main compartment (units A, B and BCPO) and deaerator construction, with seismic impacts taken into account, are in general achieved».

Next question: did the personnel of ChNPP identify the shaking it experienced as an earthquake? Personnel of shift N 5, which worked at ChNPP in the night of 26.04.86, did not hear the clatter of earthquake. Even the explosion, which demolished the unit 4, was not heard by all, nor in all rooms of the station. From almost 20 explanatory notes (which the author of this paper has at hand), which were written by the duty personnel of 26.04.86, it follows:

- personnel of the station, which was outside of the main building (*ABK*-2), noticed at first activation of the main emergency valves (*GPK*), then "awful noise" or clatter with rattle, strong vibration of the building and hollow roar, after which a shower of glowing (burning) debris of various forms and sizes;
- people who were in the main building noticed prolonged and intense low-frequency sound similar to hydro-shocks, which could be heard only in the premises adjacent to mechanical and reactor equipment (at Control Room of unit 4, in turbine building, in the premises of main circulation pumps and the like); not everybody heard these sounds – some noticed only "shaking" or "trembling" of the floor and walls (in the premises of *KRU*, "*Skala*" etc.);
- for controllers of the central Control Room of Unit 3 (adjoining Unit 4) everything began with the most powerful shocks and sounds of explosions, and then a dust fog appeared in the Control Room and sharply increased readings of radioactive background gauges;
- simultaneously with shocks, in corridors and premises of the main building of NPP (located at 9 m and higher) almost instantly a lot of dust appeared (it was compared with white fog), maybe through cable ducts, as one of the eye-witnesses commented;

- in some premises people experienced penetration of an air wave, even where doors were closed; then followed two combined blows perceived as one prolonged explosion, after which followed a third powerful blow (explosion) from some upper point (upper explosion);
- from the moment when intensive vibrations (blows) appeared, until the first explosion which was perceived by witnesses as a double prolonged explosion in the area of the core and main circulation pump (lower explosion), a time period estimated by witnesses was (an average) from 6 to 8 seconds;
- estimate of the interval between the double blow and the third – from 1 to 3 seconds;
- duration of the whole process, according to their impressions – from 7 to 11 seconds;
- those who were near the reactor premises of unit 4 noticed blows of extraordinary power, it seemed to them that monolithic concrete wall may collapse any moment.

And, at last – when did these events happen?
It is possible to arrange them (using texts of explanatory notes of the ChNPP personnel) in the following order:

1) vibration of buildings and equipment;
2) activation of emergency valves (*GPK*);
3) first and second explosions, as one prolonged explosion;
4) shaking of buildings and constructions caused by first explosions;
5) the last explosion.

It should be noticed that people who were in the lower level premises of the main building did not hear the sound of activated *GPK*. People who were in the nearby buildings not far from reactor section mentioned in their explanatory notes appreciable "shaking" simultaneously with the sound of out-through of steam through *GPK*.

Let's consider in more detail the sequence of events which was reconstructed above in accordance with evidences of witnesses.

<u>**Point 1.**</u>
At 01:20:30, growth of reactor power began (reading of the device of physical control of reactor energy release – *SFKRE*). Insignificant (within the range of regulation by the rods of automatic regulator AR) increase of reactor power was compensated by the AR-1 system, until it was fully inserted in the reactor, then an automatic power regulator AR-2 started working. By 01:23:39 the reactor power increased by 30 MW. This was initiated by the positive steam effect due to reduced water flow in the circulation loop after 01:23:04, when four MCP started working from "rundown" of TG-8. From 01:23:04 to 01:23:39 water flow decreased [6] by 5,800 m^3/h (from 56,800 to 51,000 m^3/h). In the beginning the process was gentle, decrease of flow was on the level of 180 m^3/s.

<u>**At 01:23:39**</u> (reading from teletype; from DREG reading at 01:23:40) EPS-5 signal recorded (as A.S.Diatlov, the supervisor of testing, stated, as well as it follows from explanatory notes of Metlenko G.P. and Kukhar - chief of shift ordered that senior reactor engineer should press the EPS-5 button). The EPS rods started to move down into the core, introducing negative reactivity during the first second and then positive reactivity during 2 second (thus a deficiency of EPS rods manifested itself – the so called "effect of displacements"). Reactivity from increased steam concentration in the core was added to this, since the flow rate through MCP decreased three time faster after switching off of rundown MCP 14, 24,13, 23 from bus lines of sections 8 *RA* and 8 *RB*. This happened during interval 1:23:41.3 to 1:23:41.9, most likely due to activation of MCP emergency protection when water flow rate dropped to 5000 m^3/h. There was no activation of protection due to minimal voltage on electric motors (0.75 Un, with delay of

activation 0.5-1.5 s, as indicated in [7]), because voltage on sections 8 *RA* and 8 *RB* (recorded on oscillogram) was no lower than 84% of nominal value. Approximately 3 s after disconnecting of rundown MCPs from the grid, reverse valves between MCPs and pressure pipeline started closing.

At 01:23:42 (recorded by *DREG* at 1:23:43) – appear emergency signals of reactor overpower and of exceeding power increase rate (*DREG* cycle N 135*D*).
So, not later than at 01:23:42 local power runaway commenced in the reactor with a doubling period of about 1 s, which could not be accompanied by clutter, roar and vibration of engineering structures.

At 01:23:45 – not later, shutting down of reverse valves on rundown MCPs.
At 01:23:46 (*DREG* – 1:23:47) flow rate dropped to zero through rundown MCPs and at least by 35-40 % in other MCPs [6]. This could be done only by a huge force applied from reactor. With that, impulse for closing was received by the reverse valves *Du* 300, installed on all 44 *RGK*. Besides, from 01:23:45 on the buses of 8*RB* section changes of currents began with variation 217-320 A and frequency 3 to 10 per second. They lasted about 3 s and finished when the current increased to 2170 A during the last second before the section was fully switched off at 01:23:49.
From 01:23:46 a current instability on buses of section 8 *RNA* was noticed, with a peak (looking like short circuit) at 01:23:47. Analysis of oscillograms shows that from 01:23:46 sections 8 *RB* and 8 *RNA* reflected events which happened with the pumps powered through these sections, including short circuits and failures.
It should be also noticed that during all period connected to section 8 *RNA* (after initial stages when start-up currents are much higher) that current through the section was higher by 500-550 A than the sum of nominal currents of the equipment connected to this section.

Point 2.
Activation of *GPK* (emergency valves) begins at the pressure 75 kg/cm^2 in *BS* (separator drums). Between 01:23:45 and 01:23:46 pressure in *BS* on the right side exceeded predefined level for activation of *GPK* and all 8 *GPK* were activated.
In this same cycle (N137D) *DREG* recorded activation of *BRU-K1* and sharp decrease of flow rate in *KMPC* cooling contour to 18,000 m^3/h (flow through running down MCP fell to 0). These events – cannonade from activation of *GPK*, shutting of reverse valves on MCPs, *RGKs* and from hydroshocks accompanying this process completed the phase which preceded destruction of the reactor core.

Point 3.

At 01:23:49 (in N 138 D cycle) a signal K06L005=1 was recorded. This signal spells that the pressure in the reactor space exceeds 0.15 kg/cm^2 (due to rupture of one or several fuel channels). Time period during which the prescribed level is reached is at least 1.4 s [6-8], and this causes delay of the emergency signal by the same time period. That's why the ruptures of the fuel channels should be timed at **01:23:47.**
Increased pressure in the reactor space tears lower and upper compensators of system *OR* (lower core plate structure) and system *E* (upper core plate structure). Premises of *SLA* (steam localization space), *BS* (steam separation drum) and *CZ* (central hall) get connected with the reactor space through under-reactor space and safety valves. For some time this reduces growth of pressure in reactor space.

It is quite likely that these events were perceived by witnesses as the first (lower) double explosion.

<u>Point 4.</u>

Explanations of witnesses show that the last (upper) explosion was heard 1-3 s later than "lower", i.e. approximately at 1:23:49-1:23:52. And switching off of reliable power supply, caused by the explosion, occurred at 1:23:49.

Thus it is possible to assume that the emergency process, which was accompanied by vibration, hydro-shocks and explosions began not later than 01:23:43 (beginning of power runaway) and ended not earlier than 01:23:49 (upper explosion).

Conclusions

If the calculated time of the beginning of the seismic event (at a distance 10-15 km from ChNPP) was correctly pointed out by the authors of "earthquake" papers (01:23:39), then taking into account uncertainty of the distance to epicenter, it will fall within interval 01:23:39±6 s. If we superimpose (moving closer to seismic stations) the calculated point of epicenter with coordinates ChNPP, the time when the event occurred will be 01:23:45. In this case the seismic event began immediately after the beginning of the wrecking phase of the emergency process in the reactor, which was at 01:23:43 as demonstrated above. **That's why we can state that on 26.04.86 seismic stations recorded local and powerful shakes (blows, explosions), which accompanied disastrous destruction of Chernobyl NPP unit 4.**

References

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4. Comment of the Institute of Construction Elements (НИИ строительных конструкций) (reg. № 27-799 of 29.08.95) on office memo by Doctor of Geological Science V.A. Kopejkin of 12.06.95 to Deputy Director General of ChNPP, Head of "Ukrytije" Object V.I.Kupny – "On evaluation of maximum design earthquake in the region of Chernobyl NPP" *(in Russian)*
5. Information of *MO AEP* on the issue of seismic resistance of engineering constructions of main building of Unit 3 of Chernobyl NPP. (reg. № 0240-17/132 of 19.04.95)*(in Russian)*
6. Analysis of functioning of electro-energy system of NPP in the rundown regime of turbogenerator of Unit 4 of ChNPP, report,1995 *(in Russian)*
7. Chernobyl accident, initial data for analysis. Part 2. *NIKIET*, Inv. № 270-*Ot*-3966 *(in Russian)*

Annex 1

Fragments from *DREG* data tape [7]

№ цикла Время Интервал Grцн11 Grцн12 Grцн13 Grцн14 Grцн2I Grцн22 Grцн23 Grцн24
ДРЕГ события цикла расходы теплоносителя через ГЦН

118Д 1.23.04 (04) *K07L053=1 СТОПОРНЫЕ КЛАПАНЫ ЗАКРЫТЫ
118А 1.23.06 7.25 7.15 7.47 7.17 7.35 5.67 7.30 7.45
119А 1.23.08 7.22 6.47 7.72 6.67 7.25 6.52 6.95 6.55

122Д 1.23.11 (10-11)*K07L202=0 СНЯТИЕ СИГНАЛА ПО НЕИСПРАВНОСТИ АР

127А 1.23.22 7.15 6.60 6.72 6.55 7.17 6.42 6.25 6.25
128Д 1.23.23 (22-23)*KIOL064=0 СНИЖ. ДАВЛ. ВОДЫ ВПРЫС. В КНД I

132А 1.23.36 6.92 6.72 6.42 ***5.45*** 7.25 6.12 6.02 6,12
133А 1.23.39 6.92 6.60 6.05 5.62 7.37 6.45 5.67 ***5.50***
134Д 1.23.40 (39) *K06LQI5=1 **АЗ-5 СУЗ**
134Д 1.23.40 (39) *K06L042=1 СТЕРЖНИ СОШЛИ С ВК
134Д 1.23.40 (39) *K06L040=0 НЕИСПРАВНОСТЬ ИЗМЕРИТЕЛ. ЧАСТИ 2АР
134Д 1.23.40 (39) *K06L151=1 РЕГУЛЯТОР П2-1332 ПОДКЛЮЧЕН ПРИ АЗ
134Д 1.23.40 (39) *K06L146=1 РЕГУЛЯТОР П1-1332 ПОДКЛЮЧЕН ПРИ АЗ
134Д 1.23.40 (39) *K06L143=1 РЕГУЛЯТОР П2-1332 В РЕЖИМЕ АВТ.
134Д 1.23.40 (39) *K07L202=1 ОТКЛЮЧЕНИЕ АР ПО НЕИСПРАВНОСТИ

134Д 1.23.40 (39) *KIOL045=1 РАЗГРУЗКА ТГ ПРИ АЗ-5
134А 1.23.43 7.05 7.35 5.65 5.75 7.72 6.42 ***5.50*** 5.80
135Д 1.23.43 (39-43)*K06LOI7=1 АЗСР (СНИЖ. ПЕРИОДА В ОСНОВН. ДИАПАЗОНЕ)
135Д 1.23.43 (39-43)*K06LOI6=1 АЗМ (ПРЕВ. МОЩН. В ОСНОВН. ДИАПАЗОНЕ)
135Д 1.23.43 (39-43)*K06L053=1 ПРЕВЫШЕНИЕ N АВАРИЙНЫЙ В 2УЗМ-1
135Д 1.23.43 (39-43)*K06L052=1 ПРЕВЫШЕНИЕ N АВАРИЙНЫЙ В 2УЗМ-2

135А 1.23.45 7.65 6.62 5.97 ***5.20*** 7.37 6.35 5.57 ***5.40***
136А 1.23.47 ***4.30*** ***4.85*** ***НДСТ*** ***НДСТ*** ***4.77*** ***4.02*** ***НДСТ*** ***НДСТ***

136Д 1.23.47 (45-47) *K06L20I=1 АВАРИЙНОЕ ОТКЛОНЕНИЕ УРОВНЯ В БС
136Д 1.23.47 (45-47) *K06L176=1 ПРЕВЫШЕНИЕ ДАВЛЕНИЯ В БС ПРАВ.
136Д 1.23.47 (45-47) *K06L175=1 ПРЕВЫШЕНИЕ ДАВЛЕНИЯ В БС ЛЕВ.
137А 1.23.48 Gпв1=144 Gпв2=80 Pбс1=75,2 Pбс2=88,2 Hбс11=-369 Hбс12=-300
Hбс21=+157 Hбс22=-51

137Д 1.23.48 (45-47) *K10L045=0 РАЗГРУЗКА ТГ ПРИ АЗ-5
137Д 1.23.48 (45-47) *K10L035=1 СРАБАТЫВАНИЕ БРУ-К1
138Д 1.23.49 (47-49) *K06L005=1 РОСТ ДАВЛЕНИЯ В РП
138Д 1.23.49 (47-49) *K06L034=1 НЕТ НАПРЯЖЕНИЯ 48В 1СШ

Annex 2

Fixation of discrete signals after *DREG* was switched on:

01:39:29 – appeared (maybe not for the first time, because interruption in the work of *Skala* and *DREG* was over 15 min) signals "decrease of level in the *SUZ* emergency tank" and "pressure in *BS* premises over 500 kg/m2"

01:40:01 – appeared sygnal "increased pressure in solid-tight sections (those to the right, closer to *SAOR*) over 500 kg/m2"

01:40:04 – this signal disappered

01:40:24 – signal appeared abain - "increased pressure in solid-tight sections (those to the right, closer to *SAOR*) over 500 kg/m2"

01:40:39 – pressure in *BS*right fell from 40 to 22 atm, pressure of *BS*left was not registered.

01:40:36 – level *BS*left = +750 mm.

01:40:49 – signal disappered - "increased pressure in solid-tight sections (those to the right, closer to *SAOR*) over 500 kg/m2" 01:40:49 – appearde signal – "decrease of pressure in *SUZ* pressure collector"

Annex 3

Fig. 1 Original seismogram, recorded by Norinsk station 26.04.86 г. [1]

In the upper part of the seismogram there is a mark of time when signal "goes into" the probes of seismic station. This time is defined as a sum, i.e. a time of travel of signal from epicenter to seismic station is added to the time of the beginning of the event in epicenter. From this seismogram we can find the time when the event began at epicenter (at ChNPP).

a) The signal "goes into" at 21:24:19 Greenwich time, or 01:24:19 local time.

The signal traveled (see Annex 4) 34 s. Subtraction of "travel" time gives the time when the event at ChNPP began: 01:24:19 – 34 = 01:23:45

So, the probable time of the beginning of seismic event at ChNPP - 01:23:45

Annex 4.

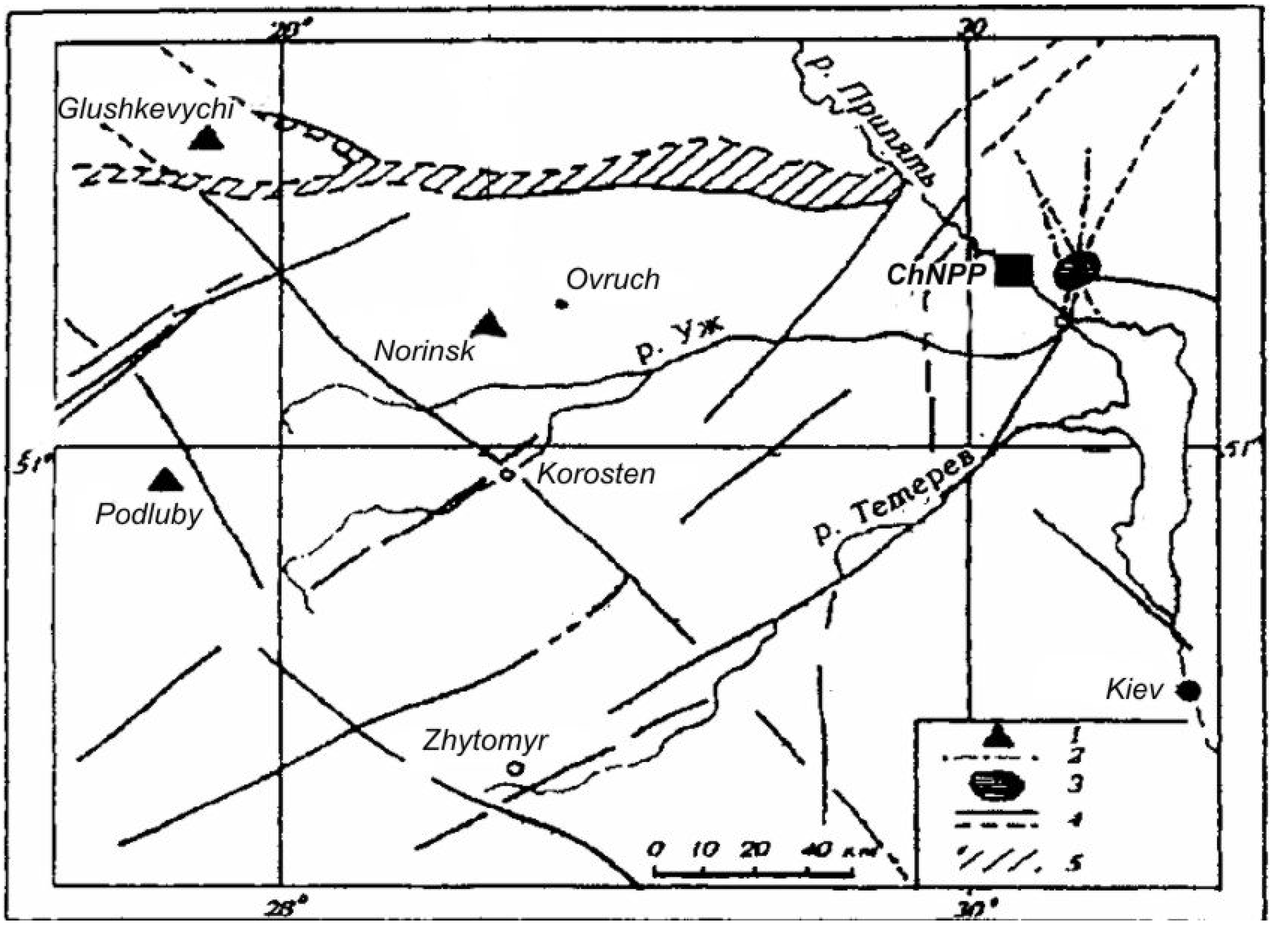


Fig 2. Map of the area [2]:

1 – seismic stations
2 – fixing location of epicenter of the event of 26 April 1986
3 – location of the zone of increased seismic emission
4 – deep faults.

Using the scale, 29 mm = 40 km, and between Norinsk and ChNPP, on the map, 75 mm. Hence the distance traveled by the signal between ChNPP and seismic station

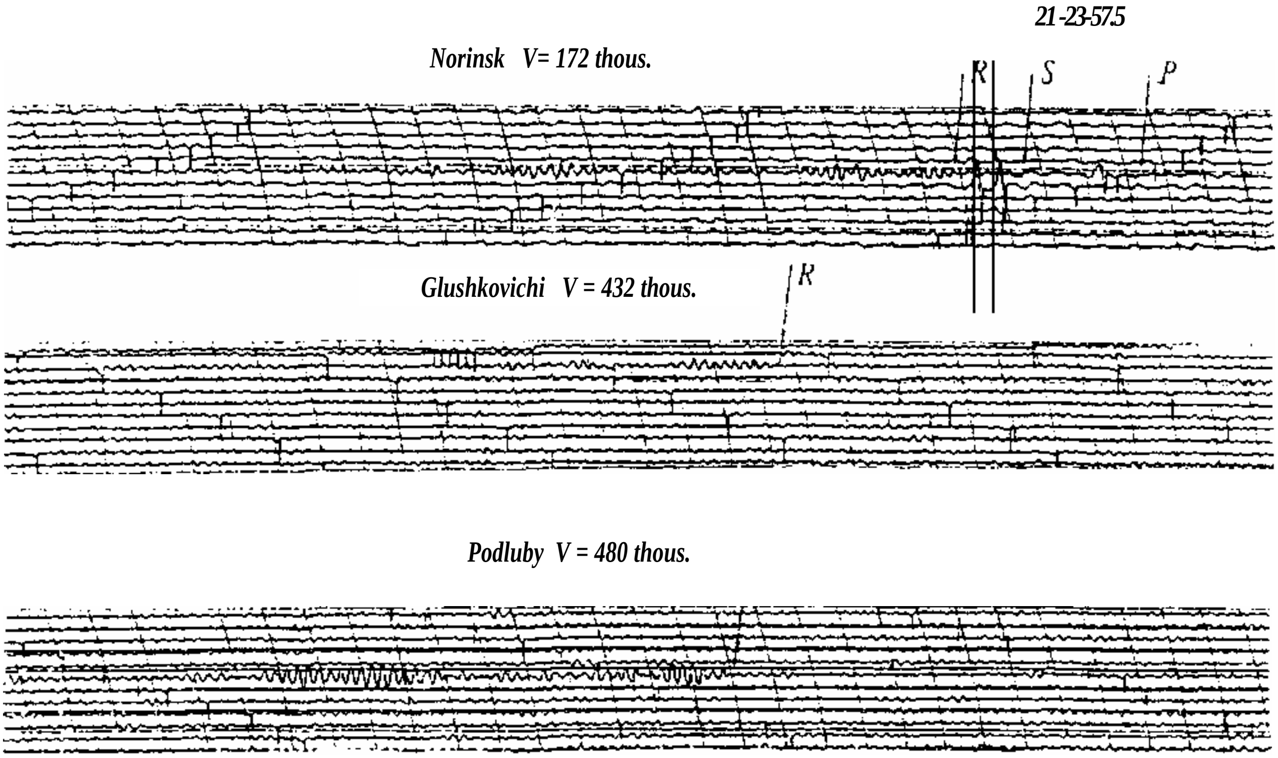
$$S = 73x40 / 29 = 100 \text{ km}.$$

Velocity of signak 2.9 km/s. From here, the time of signal delivery

$$Ts = 100/2.9 = 34 \text{ s}.$$

So, the time of travel of signal from epicenter of the event to seismic station equals 34 seconds.

Annex 5.



1 min

!____________77 mm___________!

Fig. 3. Seismograms of the event of 26 April 1986 (narrowband channels) [3].

The number of maximums on Fig.3 equals two (the first, with a wider base – looks as a double explosion; interval between maximums equals approximately 3.5 mm). Let's calculate how much time elapsed between two peaks:

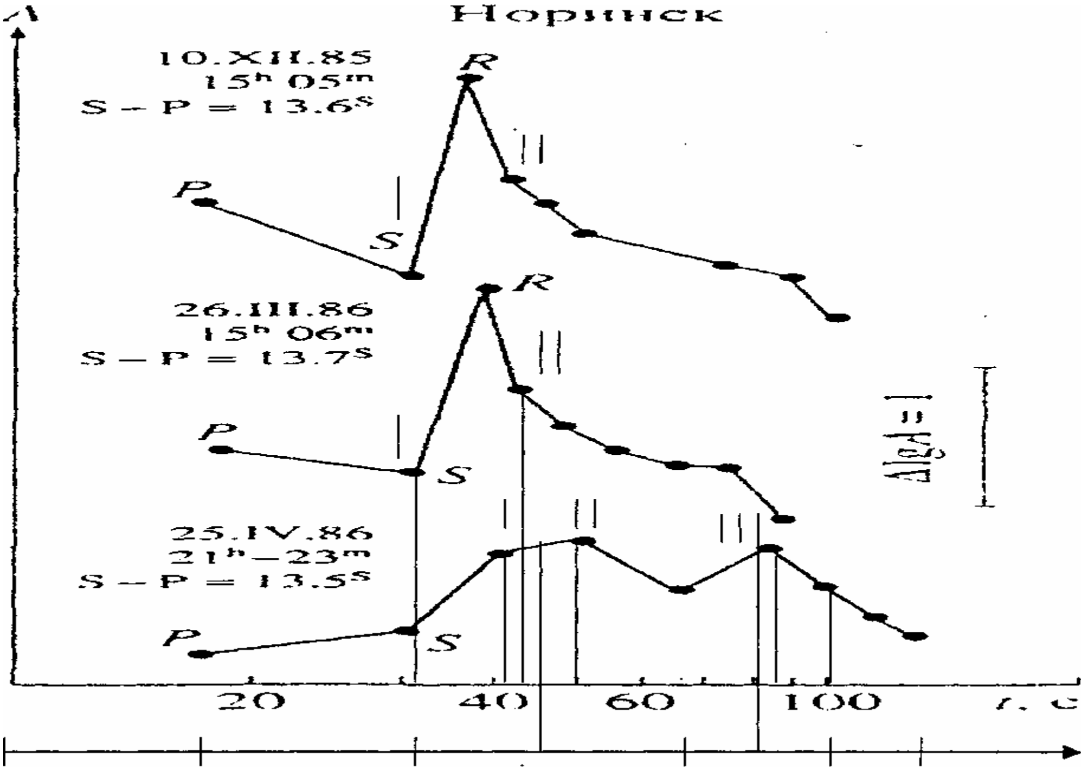
1 min = 77 mm, and between peaks – 3.5 mm. Thus, an interval between two events symbolized by these two peaks

$$T = 3.5 \times 60/77 = 2.7 \text{ s},$$

which could be considered as a time between "upper" and "lower" explosions.

So, an interval between explosions could be 2.7 seconds.

Annex 6.



X	a	b	c	d	e	Y	T, seconds
2.8 s	6.6 s	7.5s	9,5s	10.5s	11.4	12.6s	

Fig. 4. Envelope line of two explosions in quarries and the Chernobyl event (Norinsk station). Distance to the source is approximately the same in all cases.

This picture does not agree with the DREG data and explanatory notes of the personnel. It follows from the picture that the duration of seismic event was between 30-40 seconds (distance between peaks II and III, between I and III). And interval between I and II is 10 s, which does not look like a double (prolonged) explosion. If we compare lower fragment with two above, then for the explosions an interval between I and II (one event – explosion, but many dots) is over 10 seconds. It means that between dots we do not see an interval of time between two different events, but some "seismophase" of one event. Chernobyl line (lower) has three such phases – from 30 to 67 s continuous double phase (peaks I and II), and from 67 to 100 s a third phase (peak III). Then the time scale at this picture has nothing in common with the real event in epicenter. This is a time scale for "seismic echo".

But if we compare this picture with seismograms (Annexes 3 and 5) we will see, that the time interval between explosions equals 2.7 s. Due to this we can introduce a new time scale, and on this scale we can mark moments of events at epicenter. Dot b – in the middle of the base of the double (lower) explosion. Dot d – on the peak of the last explosion. Between b and d – about 3 s. Thus we can define the measure of the new time scale, 1 s = 11 mm.

Then we receive that the time interval during which shocks, shakings and explosions occurred, could be of about 10 s (from X to Y).

Continuous (lower) explosion could sound up to 3 s.

(Translated from Russian to English by V. Tykhyy)

Chornobyl: The Danger for the Global Civilization

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1.

I was born in Kiev in 1934. Kiev is the ancient capital of Rus-Ukraine with more than 1500-year history. Built on high hills above Dnieper – one of the biggest rivers in Europe – Kiev is famous for its ancient churches, monuments of history and architecture.

I remember the beginning of the German-Soviet war in June 1941: German aircrafts bombing Kiev, the Red Army retreating and our family evacuating from Kiev to Russia. We came back only in 1944 and found the native city burned and ruined. In 1958, I graduated from the Kiev Medical University and became an epidemiologist. I worked at the Research Center for Epidemiology and Infectious Diseases and took part in the fight against outbreaks of such diseases as abdominal typhoid, diarrhea, cholera, brucellosis, rabies, and other viral infections. While working in Asia, I witnessed plague and leprosy.

As a doctor, I traveled all over Ukraine, visited hundreds of villages and small towns. But until 1986, I had never been to Chornobyl.

Before the Chornobyl accident, I had never been interested in nuclear power and had only a very rough idea of what a nuclear power station was and of how a nuclear reactor operated. At the height of the Cold war, in the 1960-1980ies, citizens of the USSR were frightened by the nuclear war, the possibility of nuclear-missile strokes by the United States at the territory of the Soviet Union. We knew well about those horrors which befell Hiroshima and Nagasaki in 1945 and sympathized with the Japanese who suffered from the nuclear weapon.

In one of my surrealistic poems (I became a writer and published, starting from the sixties, novels, stories, poems and essays), I quoted data from the American book entitled The Medical Effects of the Atomic Bombs in Japan. I was amazed by the story of a Japanese mother who covered her child with her body and saved him from death in that way. The power of love turned out to be insurmountable for cruel gamma rays and neutron flows!

Despite all that, the possibility of a nuclear accident in the USSR never crossed our minds: we lived in hermetically closed totalitarian society with powerful propaganda machinery – one might say the Ministry of Lie – and almighty censorship. Until 1986, we did not know about nuclear accidents in the Soviet Union because all such information was classified.

2.

Saturday, April 26, 1986, was sunny and warm in Kiev: it was one of those really nice spring days when the weather causes joy to people tired because of long winter, March thaws and frost - during such days most of Kievers would go out. The trees had already become green. The first brave people bathed in Dnieper and sunbathed in suburban forests.

On that day we celebrated the birthday of a friend of mine – a well-known Kiev professor-physician. In the afternoon we went out to the balcony where we basked in the sun and took pleasure in the simple joys of life.

Suddenly, my friend said, “I had a call from the central hospital – they said something had happened at the Chornobyl nuclear power plant. Some accident. Victims were brought to the hospital.”

“It is quite possible,” I said carelessly, “Perhaps, they got burned by steam or were injured.”

My friend agreed. It did not cross our minds that on that day the humankind turned a new page in its history.

3.

Rumors about the terrible accident at the Chornobyl nuclear power plant (NPP) quickly spread all over Kiev. No one knew for certain what had happened there but there was no trace of carelessness in conversations. On the contrary, anxiety rose in the absence of official information. There were unbelievable rumors about thousands of victims, the imminent risk of a massive explosion at the plant and a possible evacuation of Kiev.

The first official communiqués were very brief and did not give a slightest idea of what was really going on at the Chornobyl NPP. A group of journalists from governmental newspapers Pravda, Izvestia and others started to publish reports from the scene of the events, focusing on feats of firemen and plant personnel. However, those publications provided no information about the issue millions of people in Ukraine and Belarus worried about – the danger posed to health, especially to children, by the radioactive substances with which the air, water and soil around the plant were contaminated.

All information regarding the level of radiation was subject to severe censorship and this fact frightened people even more. Everyone recalled Hiroshima and Nagasaki and no one believed the optimistic propaganda of the communist regime. Elderly people recalled the official propaganda lying in 1941 in attempt to conceal the truth about terrible losses of the Red Army in the beginning of the war.

History repeated itself. The policy of “glasnost”, proclaimed by the Secretary General of the Central Committee of the CPSU Michael Gorbachev in 1985, did not stand the first test and was compromised by the bureaucratic system which cared not about people, their physical and moral health but about the preservation of the authoritarian state model.

A friend of mine who happened to be in the building of the Central Committee of the Communist Party of Ukraine at that time told me that panic was reigning there. There was a long line to the in-house rail ticket office – the Committee staff bought tickets to take their families out of Kiev. At the same time, one of Kiev top officials, asked whether children should be taken out of the city, said, “We do not worry about Chornobyl. It worries us more whether vodka should be sold during holidays” (he meant the 1st of May – an official Soviet holiday; at that time, the fight against consumption of alcoholic drinks, initiated by M. Gorbachev, became a state doctrine).

On May 1, 1986, traditional Communist demonstrations were held in all cities and towns of Ukraine, including Kiev and areas neighboring the Chornobyl NPP: tens of thousands of schoolchildren were taken out in the street to create a festive mood. Later there was information that a part of Ukrainian leaders insisted on cancellation of the manifestations, which jeopardized children. Nevertheless, the head of the Ukrainian communists, dogmatist V. Scherbytsky, came to the demonstration with his 10-year old grandson, trying to set an example for his fellow party members.

Hypertrophy of thyroid gland and other health anomalies were detected later in many of the children who took part in those demonstrations.

4.

In 1984, I abandoned medical and scientific activities and totally devoted myself to literature. Now I had time for writing stories, novels and plays. Simultaneously, I worked as a correspondent for the popular Moscow newspaper Literaturnaja Gazeta (Litarary Newspaper) and magazine Junost (Youth). At that time, those were liberal periodicals that supported Gorbachov’s perestroika and published bold articles about the situation in the Soviet Union. I also contributed to some Ukrainian newspapers and magazines. The communist regime liberalized little by little, and true articles appeared on the pages of progressive periodicals more and more often.

However, in the case of the Chornobyl catastrophe, the old Stalin syndrome showed itself – no truth about the scale and consequences of the accident should have gotten out. Only articles full of official optimism were published.

People read and reread the official information, trying to understand something by reading the truth between the lines, but without success.

In the end of April – in the beginning of May, I discussed the problem with a friend of mine who was a representative of the Literaturnaja Gazeta in Kiev and we decided to try to get into the closed zone to find out at least a particle of truth. By then, there were no representatives of the Literaturnaja Gazeta in the zone – they were not allowed to write about the catastrophe. I expressed my wish to go to Chornobyl voluntarily, as a doctor-epidemiologist, and to write a series of articles for the Literaturnaja Gazeta about everything I would see there.

The Ministry of Health of Ukraine, where I went to obtain a permission to enter the zone of the catastrophe, was in a total mess and confusion. The Minister was in the United States and one of his deputies – the person with whom I used to work at the laboratory – acted for him. I made my way to his office and offered my help in informing the population about how to behave in conditions of a nuclear catastrophe. He waved me away and quite harshly said (before that we were considered friends) that it was not my business. He told me they knew themselves what to do.

Later I learned that there was a severe order of higher leaders hanging over him and other members of nomenclatura - to do all they can to keep the secret of the Chornobyl accident and its aftermath. In fact, that was a criminal order but, unfortunately, doctors had to execute it.

In a corridor of the Ministry, I was approached by a familiar radiologist, who whispered to me that the situation was very serious: the wind drove the radioactive clouds from the north towards Kiev. He recommended me to shut windows at home tightly, keep small children indoors and give all members of my family iodine in order to block thyroid from consumption of radioactive iodine. I was grateful to him for his advice.

I went to the drugstore situated near the Ministry of Health, in Lypky district – the area of governmental buildings and apartment houses for high state officials. There was quite a long line consisting mostly of pensioners. To my great surprise, everybody in the line asked for solution of potassium iodine! It turned out that doctors from the governmental policlinic (the so-called 4th Department) had recommended their patients to carry out iodine prophylaxis. At the same time, millions of people that were in the zone of the accident had not been even informed about the nuclear catastrophe!

That warm and sunny day is engraved in my memory: thousands of men and women walking in the street; children playing, as usual, in send-boxes in parks; people lining up to buy sneakers, canned green peas or some other scarce goods.

I was overflowed with the feeling of danger approaching the city. In the small square at Prorizna Street I said to a young mother playing with two children, “Take them away, it’s dangerous – there is radiation!” She looked at me as if I were crazy and harshly said, “Stop panicking. Go away and do not bother me.” That was the end of my attempts to save the younger generation of Kievers.

Only in the yard of my house I approached my neighbors who had a child born shortly before the accident and told them about the situation. They took the child immediately indoors and until now are grateful to me for the warning.

5.

The editors of the Literaturnaja Gazeta wrote a letter to the Minister of Health of Ukraine Dr. Romanenko. He finally came back from the USA – just when the wave of panic was growing. The Minister ordered to create a special medical group consisting of three professors – one from the Institute of Oncology, another one from the Institute of Endocrinology and me, in capacity of a doctor-epidemiologist with wide experience of fighting against various epidemics. It took three or four days to pass all bureaucratic procedures.

Finally, in the beginning of May, after all permissions and passes had been received, our medical car went to the north - to the regions directly neighboring the zone of the catastrophe.

The highway leading to the Chornobyl zone ran through a picturesque area near Dnieper, but everything that we saw was rather gloomy and disquieting – the highway reminded us of battlefront roads.

There were columns of military trucks and trailers laden with bulldozers and engineering equipment going towards the Chornobyl NPP. Vehicles with cattle slowly moved in the opposite direction. Poor cows - taken out of the radioactive zone, they did not know that they were conveyed to slaughterhouses! There were big problems with utilization of skins – the hair of cows was covered with large amounts of radioactive dust.

Villages looked extinct. The nature celebrated springtime: trees were in blossom, rivulets were filled with water and verdure was sappy.

The road traffic was regulated by officers of highway patrol police. I noticed their unnaturally red faces. I thought they had become sunburnt but I found out that the redness was caused by alpha-burns produced by radioactive dust. Many of those traffic-controllers did not have respirators and inhaled air contaminated with radioactive particles. Subsequently many of them became invalids.

One of my fellow travelers was joking all the time and commented on everything in an excited and ironic manner. We laughed loudly, as if we had taken a sip of good wine. This was a manifestation of the fear of the unknown - soldiers often felt that way when they approached a battlefield. The other doctor was more reserved. Later he became a leading expert in the field of endocrine diseases caused by the Chornobyl accident.

Our destination was Polisky and Invankivsky districts, which neighbored the place of the catastrophe and to which tens of thousands of evacuees from the 10-km zone were taken. Subsequently the area of alienation was enlarged to 30 km.

We had to evaluate the medical situation on the spot, give necessary consultations to local doctors and provide assistance in organizing preventive measures.

What we saw struck us: living 100 km from the zone of the catastrophe, we had no information about what was really going on near Kiev. The scale of those events reminded war: tens of thousands of evacuees, families who lost connection with their relatives and friends, numerous field hospitals and laboratories and hundreds of medical teams. Ambulance cars carried number plates from all regions of Ukraine. Hospitals were overcrowded. Offices of head doctors looked like improvised headquarters, where pressing decisions were taken regarding assessment of the radiation situation, ensuring monitoring of the radiation level of drinking water and foodstuffs, and organization of life of numerous medical personnel who came to the area of the catastrophe.

Absence of any reliable information regarding the level of radiation pollution of the area around the Chornobyl NPP was the main problem at that time. This information, which was available to the emergency governmental commission working in Chornobyl, was strictly secret. To assess the level of radioactive pollution of nearby areas, local health authorities had to use their own dosimeters designed for wartime and not sufficiently precise.

We met our colleagues–doctors and saw first victims of the accident at the plant. A local obstetrician-gynecologist told me that in the first days after the catastrophe, many pregnant women, succumbing to panic and being afraid to give birth to children-monstrosities, had abortions.

Another doctor took us to a hospital basement, where piles of mattresses, pillows and blankets lay. All that stuff remained after the first wave of mass evacuation and was extremely polluted with radioactive nuclides – as they said then, it "glowed". Doctors did not know what to do with that – they encountered such problem for the first time.

It was during the first trip to the catastrophe zone that I started to record tapes. At first, I did not have any clear plan – I just wanted to record the most interesting stories about the catastrophe to use in my articles. However, soon I realized how powerful these materials could be if one would conduct a system questioning of everybody relating to the accident at the Chornobyl NPP and to overcoming of its consequences.

I started to collect testimonies purposefully and, in half a year, I had a big collection of tape records – from an academician to a student, from a NPP operator to a doctor, and from a farmer to a military helicopter pilot.

These records became a basis of the documentary story Chornobyl published in 1987. I still keep those old tapes – evidence of our tragic history, out of which the whole humankind should make conclusions.

6.

I got to Chornobyl just in a couple of days after the first trip. After passing several checkpoints, we drove into a desert highway, covered with some white substance, which led to Chornobyl.

I was really terrified. For the first time in life, I looked into an incredible, unnatural world of beyond – the world that no one on earth had seen before. I saw a nice Ukrainian small town with ancient history, in which destinies of Ukrainians, Poles, Jews and Russians intertwined. The town was desert, extinct, without usual almost countrylike, unhurried life. Shutters of one-storey wooden houses were tightly closed; a big padlock was hanging on the door of a church; all stores and institutions were locked and sealed. Life was in full swing only in front of the building of the District Committee of the Communist Party, where the governmental commission worked, but that was specific, half-military life. There were radio stations and armored troop carriers under masking net. Tens of black cars belonging to Kiev senior officials were parked nearby. These cars, which collected a lot of radiation, remained in the zone forever in a special "graveyard".

It should be explained that Chornobyl, as an administrative center of Chornobyl district, did not practically relate to the nuclear power plant, which was built in 18 km to the north-west. The town only lent to the plant its name, which became world-known. The service personnel of the plant lived in the new town of Prypyat - much more modern than Chornobyl and located at the distance of 2-3 km from the plant. Prypyat, which consisted of comfortable apartment houses, was immediately covered with a radioactive cloud. The population of the town - more than 50 thousand persons - was evacuated in 24 hours after the accident, and the town practically ceased to exist. Prypyat became a sui generis Atlantis of the nuclear era, having disappeared forever.

The town of Chornobyl became a place of location of the governmental commission for combating the consequences of the catastrophe, headquarters of various research and engineering organizations, canteens and residences for those who participated in the liquidation of the accident aftermath.

New inhabitants of Chornobyl – mainly men – were dressed in white or green overalls of NPP staff or camouflage military uniform. Because of this circumstance, the town gave an impression of being on a front-line.

I went to Chornobyl and Prypyat regularly (in fact, that was half-legal): first, together with doctors from the Ministry of Interior who were friends of mine, later with acquaintances from the Institute for Nuclear Research of the Academy of Sciences, who told me a lot of interesting facts – about possible causes of the explosion, about the radiation state in the zone and about the imminent danger of a new explosion.

The matter was that there were tons of radioactive water accumulated in the room under the nuclear reactor (so called bubbling chamber). If the red-hot core of the blazing 4th reactor had burned through the concrete floor and fallen into water, an extremely powerful steam explosion would have taken place and could have destroyed the 3rd reactor adjacent to the 4th one. Consequences of this new catastrophe could have been much more terrible than the effect of the events of April 26, 1986.

Now all efforts were directed at pumping water out of the bubbling chamber. Several teams of firemen, working in the zone of very high radiation, tried to bring fire-hoses to the bubbling chamber and to set pumps. I had an occasion to be in Chornobyl during those critical days. I saw pale, tired firemen, who had performed the dangerous work and come to a medical center for a checkup. I remember one officer said, "Now we can celebrate one more Victory day. There will be no explosion".

7.

During those days panic in Kiev escalated to a breaking point. At the railway station, thousands of people stormed trains heading to Moscow. People tried to take children and grandchildren out of the city in the first place. Columns of cars were moving to the west and east of Kiev – in direction of Lviv and Poltava, which were not affected by radiation. Whole families were leaving, not believing in soothing words of the official propaganda.

In case of a new, steam explosion at the NPP, the whole Kiev was supposed to be evacuated. When I learned about that, I suggested to my mother preparing herself to the possible rapid evacuation. Mother, who was then 82 years old, looked at me sadly and said, "No, son. I already evacuated in 1941. I will go nowhere from the city anymore. You take the family and go. I will stay. I want to die here."

Luckily, the evacuation of Kiev did not happen, but I remembered the sad mother's voice and her refusal to leave the family nest for the rest of my life. I imagined that there would be a lot of people like my mother in the empty city. What would these old, infirm people do? What would their children do, being forced to leave their home?

Friends of mine gave me a dosimeter and my children amused themselves by measuring the level of radiation at our balcony. The readings exceeded background levels hundreds of times.

In the beginning of May, production of a film based on my scenario started in Kiev. A famous Moscow actor was invited for the role of the main hero. Everyone in the Soviet Union knew him for his role of a secret-service agent in a popular TV serial. In that film, the Russian agent somehow became a general of SS and, while working in Berlin, informed the Russian leadership about Hitler's plans.

I went to meet the actor at the railway station. The morning train from Moscow arrived almost empty. A group of officers came out of it, met by other military men. Several casuals looked round frightened as if asking what happened in this radioactive Kiev to which they were so scared to go.

Finally, an elegant gentleman came out of the first class carriage. I recognized him immediately – that was the famous actor. He asked me angrily, "What is the mess going on here? Somebody spreads rumors about the scale of the accident. I have just come back from Austria, and they unleash an anti-Soviet campaign. They want to present us as a threat to the West in the interests of NATO. Don't people in Kiev understand that? How can you succumb to propaganda of enemies?"

My efforts to explain him something were futile. We came to my house to have lunch. I asked him to take off his shoes on the doorstep, and my son passed the Geiger counter over his boots. The level of radiation was higher than the biggest scale mark of the counter. We showed the readings of the counter at the balcony covered with dust to the actor. Nevertheless, he refused to believe, being convinced that Kievers had become victims of anti-Soviet propaganda.

The next day he was filmed in a scene in the streets of Kiev in the course of the International Cycle Race. At the time when Western states refused to participate, the Soviet Union satellites – Poland, Czechoslovakia and others – sent their teams to the competition. To our horror, we could watch young well-trained men pumping over their lungs the Kiev air polluted with radioactive nuclides and "hot particles".

Another shooting took place in the Institute of Neurosurgery: the actor played the role of a prominent Kiev cybernetician who was diagnosed with brain tumor. In the diagnostic laboratory, where the episode was filmed, we were told that they had stopped their activities because the level of radiation exceeded the allowable maximum hundreds (!) of times.

This information played a decisive role. The actor, who had accused Kievers (including me) of panic and Western governments of unleashing enmity towards the USSR, suddenly threw off his mask of a hero, turned pale, became pitiable and recalled his diseases that required him to return to Moscow promptly. Having spent incomplete three days in Kiev, he fled from the city infamously and disappeared forever.

I gathered a significant part of the information about the catastrophe, which became a basis for the documentary story Chornobyl, at Kiev hospitals where victims of the accident - NPP operators, firemen, military men and constructors – underwent medical treatment.

Those who received the highest doses of radiation were taken to Moscow by plane to a special hospital No. 6. The main indication of acute radiation sickness was irrepressible vomiting, which was evidence of the received dose above 100 rads (the annual allowable dose for NPP personnel was 5 rads!).

Some of the victims were doomed to death since their radiation doses were incompatible with life. Those people died despite all efforts of doctors. Even Dr. Robert Gale – the Head of the UCLA Center for Bone Marrow Transplantation (USA) - did not help them. I met this youthful swarthy doctor in Kiev in June 1986 when he came for the first time to visit local clinics. Thanks to television, the doctor became the most popular American in the Soviet Union.

We met each other repeatedly during Dr. Gale's visits to Kiev – at hospitals and international conferences. In 1996 – the year of 10th anniversary of the Chornobyl catastrophe – I met him in Washington, where I served as the Ambassador of Ukraine to the USA. Robert Gale was going through hard times of his life: several American doctors accused him of self-advertisement and of inadmissible commercial use of terrible pictures of patients from the Moscow hospital No. 6 (Gale published them in the popular magazine National Geographic). In the United States, there was a good film produced on the basis of his scenario about the Chornobyl events. Our meeting was cordial – we had memories to share about the days of the Chornobyl disaster.

At one of Kiev hospitals I met Mayor Leonid Telyatnikov, Hero of the Soviet Union and head of the military-fire unit No.2 of the Chornobyl NPP. On the day of the accident, Telyatnikov was on leave but, having received a distress call, he immediately went to the station. Having climbed on the roof, he saw that it was burning in several places above the 3rd block. The block still functioned and, if the roof had fallen to the reactor, the country and the world would have faced a catastrophe much more horrible than the 4th block explosion. Telyatnikov told me how he and his firemen had extinguished fire on the roof and how he had felt unwell after two hours of this infernal work - that was the beginning of acute radiation sickness.

Thanks to Telyatnikov, I – and my readers together with me – learned the details of deaths of those firemen who rushed to extinguish fire in the reactor compartment of the exploded 4th block, ignoring radiation hazard (and, actually, not knowing seriously anything about it). They perished themselves in the radiation flame of the catastrophe…

Many acquaintances of Telyatnikov testified that he had come to the fire straight after a wedding, being not sober. Some nuclear specialists believed that alcohol protected from radiation and that explained Telyatnikov's survival despite the high level of radiation on the roof. Alcohol abuse "as a preventive measure" was widespread in the zone.

During two years – 1986 and 1987 – I regularly visited Chornobyl, Prypyat, the NPP and its surroundings to collect materials for the story.

During that time I lived simultaneously in two worlds. The new one was an absolutely incredible world of the nuclear catastrophe which seemed to come to the earth from the distant future, symbolizing the end of civilization. Coming back to Kiev, I immersed into the ordinary life with its usual joys and concerns – far from nuclear nightmares. In the former times, this second life had sometimes looked monotonous and boring but now, compared to the anti-world that appeared in the zone of the Chornobyl catastrophe, it seemed magnificent. Similarly, the lost peace appears so wonderful when there is war raging around. Those who were not in the zone during those days did not understand me: I felt delight in the most commonplace details of the city life – even operation of the subway, no-break power, regular watering of streets to wash away radioactive nuclides, removal of leaves polluted with radiation, control of radiation level of foodstuffs at markets, organized sending of children to the regions of Ukraine free from radiation and so on.

Panic of the first half of May 1986 has subsided, and inhabitants of Kiev got used to living under radioactive hazard - "spots" of increased radiation were detected at rooftops, in parks and on hillsides near Dnieper. Although maps of radioactive contamination remained secret, civilian defense forces and local authorities made efforts to deactivate the dangerous zones: top layer of soil in parks was collected and taken out of the city; buildings and playgrounds were thoroughly cleansed. It was much more difficult to ensure such measures in rural districts near the Chornobyl NPP: it was necessary to organize supply of milk to villages (farmers' cows that had collected radiation were slaughtered), delivery of drinking water (wells were polluted with radioactive nuclides), vegetables, bread and meet. The size of radioactive pollution zones was regularly assessed and, in a number of cases, decisions about resettlement of inhabitants of certain villages in "clean" regions of Ukraine were taken.

My first publications in Moscow and Kiev periodicals about the situation in the zone of the accident generated great interest and I started to receive hundreds of letters. I still keep these moving human documents of time, which give an idea of the gigantic scale of the events that affected destinies of millions of people in Ukraine, Belarus, Russia, other republics of the Soviet Union and neighboring countries.

During those days I often spoke in public in Kiev and was asked the most unexpected questions, answers to some of which I did not know then. I had a persistent feeling that an abrupt shift in the mood of most people took place in the country (at least in Ukraine). In fact, the USSR – once a seemingly imperishable empire whose territory stretched from the Kuril Islands to Berlin – started to dissolve in the hot summer of 1986. The state that was called the Empire of Evil was collapsing in the souls of people who had not forgiven the ruling Communist Party for lie and cynical ignoring of danger posed to children's health.

Never being a member of the Communist Party, I was surprised by the sharpness of the criticism directed at Ukrainian and Soviet leaders, expressed by seemingly orthodox communists during various meetings. The era of Gorbachov, who advanced slogans of “perestroika” and “glasnost”, began from very deep public disillusionment over the ruling system of that day. This process, first unnoticed not only by western observers but also by Soviet political scientists, led to serious consequences in 1991 when the Soviet Union dissolved.

However, then, in 1986, few people thought about the incipient chain reaction that subsequently led to the USSR demise. The question about whose fault was the Chornobyl catastrophe seemed much more important. What did really happen at the plant on the night of April 26, 1986? Why the country turned out to be so unprepared to the biggest man-caused accident of the 20th century?

8.

I advanced towards my own understanding of the causes and consequences of the catastrophe slowly and practically blindly. That path was not easy – from the first, sometimes accidental impressions and meetings, from narrow perception of the scale and peculiarities of the catastrophe to comprehension of philosophical, political and social roots of Chornobyl. The work on the book Chornobyl (Moscow, Sovetskij pisatel Publishing House, 1991) took four years of my life – four years of intensive search for the truth, meetings, trips and study of documentary evidence of what had happened.

As I delved into the topic, professional secrets of the Chornobyl nuclear power plant revealed themselves to me. Thanks to testimonies of witnesses, it became possible to reconstitute the picture of what was happening during that terrible night in the premises where fatal decisions regarding conduct of an experiment with the nuclear reactor and energy-generating turbine were taken. Experts taking part in investigation of causes of the accident helped me (and my readers) to understand the sense of those events in greater detail.

If, during the trial, which took place in 1987 in Chornobyl, the main blame was put on the NPP top managers and operators of the 4th block, in the course of a more thorough study of all circumstances, it became clear that the RBMK reactor itself was imperfect and had become a source of increased danger. Being a typical military reactor designed to produce plutonium for atomic bombs, the RBMK reactor was characterized by instability: physical specifications of RBMK operation at reduced capacity were understudied, and reactor rods conduced, under certain conditions, to a sharp increase of reactor capacity, up to an explosion. All this resembled a situation when a driver, wishing to stop his car suddenly, steps on a break, but the car accelerates instead.

Certainly, the accident might have not happened, if it were not for the outrageous mistakes of the personnel who performed inadmissible experiments in the nighttime and turned off the systems of reactor protection. All this was evidence of serious problems that existed in the Soviet nuclear-power system – from reactor designers to ordinary operators.

I was greatly impressed by a meeting with one of the leading nuclear scientists, academician Valery Legasov, Deputy Director of the famous Moscow Kurchatov Institute, who was a member of the governmental commission working in Chornobyl. He was a man of great civic courage and scientific integrity, who was one of the first to understand that what had happened at the Chornobyl NPP was not an incident and not only an operators’ fault but a natural result of development of the Soviet system which was based on non-professionalism, lie and careerism.

For the first time in the USSR, he told the bitter truth saying that now not human-beings should be protected from technology but technology (complex and superpower) should be protected from human-beings. He was one of the first to understand that the RBMK reactor – the favorite brainchild of President of the USSR Academy of Sciences Alexandrov – was imperfect. This discovery of Legasov undermined the myth about complete safety of the reactor, which was propagated by its designers. Many of Legasov's colleagues and Communist party leaders did not like this truth. The end of Legasov was tragic: he committed suicide on the anniversary of the Chornobyl catastrophe. Academician Legasov, who told the truth about the accident, became one of the victims of Chornobyl. My meeting with him remains one of the unforgettable events in my life.

For me, the dead town of NPP personnel Prypyat, in which more than 50 thousand people lived prior to the accident, became a symbol of the Chornobyl catastrophe and a bitter warning for the humankind.

The radioactive cloud that formed after the 4th reactor exploded immediately covered this beautiful modern town. There are amateur videos showing how the peaceful life of the doomed town passed – children playing on playgrounds, friends congratulating a newly wedded couple, people having rest – and no one thinks of the terrible danger threatening the inhabitants of Prypyat. At first, authorities tried to do everything possible to create an appearance of normality, but a sharply increasing level of radiation in the town forced them to make a dramatic decision – to evacuate the whole population of Prypyat, leaving only those who were engaged in salvage operations.

The decision about the evacuation was taken late at night on April 26 (the accident took place at 1:23 A.M. on April 26). Preparation for the evacuation took place all night long: more than a thousand buses were gathered, and in the early morning of April 27 (Sunday) they came to Prypyat and were parked in several town districts. Evacuees were allowed to take one bag (suitcase) with personal belongings. Stupefied by the necessity to evacuate, people were in shock. Many of them did not have time to take the most necessary. And what is more, they were leaving the town not for several days, as they were told, but forever.

FOREVER.

Even today, 20 years after the catastrophe, for many inhabitants of Prypyat, the memory of evacuation is the most painful. The peaceful life of thousands of people was tumbling down. This is reflected in the language of eyewitnesses of those events, who say "before WAR" (i.e., before April 26, 1986) and "then there was WAR." The explosion at the Chornobyl nuclear power plant divided time into two parts – time before war (peaceful and beautiful) and time of suffering.

For the first time in the history of the humankind, a dead town appeared on the map of Europe during a peaceful period. In 1986-1987, I visited this phantom city dozens of times; I was in its houses deserted forever. 16- and 9-storied white buildings stood in silence. Building cranes froze forever over construction sites. The market place had turned into an auto graveyard with hundreds of cars rusting in the open air. Birds had left this dead city; no cats or dogs were seen. A building in the center was crowned by giant letters making a surrealistically sounding slogan of Soviet physicists, who were optimists before 1986, - "May atom be a worker not a warrior." Wild grass grew through cracks in concrete, and white river sand drifted at the central square.

The town was sinking into non-existence as once Aztec buildings did. Maybe in a thousand years, archaeologists of the future will dig out the perished town – the monument of the nuclear catastrophe caused by human beings.

It seems I will remember forever the sickening smell of the dead town and the existential sadness of parting with life that I felt in this zone of high radiation.

From all warnings given to the humankind, Prypyat is, perhaps, the most sinister. Do not play with the nuclear genie. This artificial creature, after coming out of the bottle, may destroy life on earth.

9.

On the early morning of April 26, 1986, after the night explosion, several NPP operators made their way, with great difficulty, to the room from which the flank of the 4th block was seen. There were heaps of debris, torn-away slabs and wall panels everywhere. Water was gushing out of torn fire-mains. The room was covered with gloomy dark-grey dust. Fragments of reactor graphite were scattered all over the place.

"What we saw was so horrifying that we were afraid to express that aloud", recalled a participant of that expedition to the edge of the nuclear night, saved by a miracle. – "The generous spring sun is shining over the ruins, over this terrible invisible danger. The mind refuses to believe that the most terrible thing has happened. But this has already become a reality, a fact. The reactor exploded. The explosion threw out of the reactor cavity 190 tons of fuel with fission products, together with reactor graphite."

For those who were first to realize what had happened, that was equal to admitting the end of the world. That was nuclear hell.

The first feeling of the NPP personnel – from the director to operators – was a DISBELIEF in what had happened. I was astonished at this conservatism of so-called "professionals", the dullness of their thinking. Their confidence in designers' infallibility and reliability of the RBMK reactor was so strong and limitless that they refused to believe that the maximum hypothetical accident had taken place. Probably, people of the Earth, having learned that they planet is splitting up, would refuse to believe that in a similar way.

The lack of imagination, the technocratic philosophy of dull rationalism, the monopoly of a narrow group of scientists and technicians, who imposed their creature on society, the lack of objective expertise and other reasons contributed to the disaster.

This is one of the first lessons of Chornobyl: it is necessary to take into account an ever increasing danger for civilization emanating from technological supersystems - energy, biological, chemical and informational - which can go out of control as their complexity and capacity concentration increase.

That is why Chornobyl was not an ordinary accident. That was a challenge to sustainable development of the humankind, an alert sent to us from the future. Chornobyl raised the question of dead-end ways of technical civilization development.

The Chornobyl catastrophe is characterized by involvement of multimillion population masses (children in the first place), emergence of hundred thousands of environmental refugees, long-term radioactive pollution of soil, water (including groundwater) and air, irreversible change in the natural environment and a number of ecosystems. In the Chornobyl zone, the nature has returned to its wild state, to the medieval period.

Chornobyl participants and witnesses went through a severe psychological shock; many of them suffered a peculiar syndrome of "the end of the world" characterized by paralysis of the will to live, loss of all hopes, apathy, loss of libido, and suicidal tendency.

Chornobyl also emphasized the problem of efficiency of the state-political system that existed in the Soviet Union. All state and public mechanisms were subjected to a stability test – above all, those relating to quick decision-making on issues concerning security of millions of people. The totalitarian monopolistic one-party system of the Soviet Union did not survive the Chornobyl test. The USSR decline started from the Chornobyl catastrophe, as a result of which the communist system lost its credibility among the people.

The Chornobyl explosion caused a burst of public indignation over the system of official lies and concealment of truth. As a result of this, an environmental and political opposition quickly formed in

Ukraine. On the tide of this public discontent, I (at that time, the leader of Ukrainian environmental movement "Green World" and of the Green Party) was elected to the Supreme Soviet of the USSR. I fulfilled my election pledges – to tell the truth about Chornobyl. As the Head of the Subcommittee for Nuclear Power and Nuclear Ecology of the Committee for Environment of the USSR Supreme Soviet I initiated, for the first time in the history of the Soviet Union, hearings about the Chornobyl problem. By joint efforts, we tore down the curtain of secrecy created in 1986-1987 by nuclear- and military-industrial complexes.

Chornobyl drew attention to the problem of political stability of any state possessing nuclear reactors on its territory and to the related problem of international terrorism. It is not difficult to imagine possible explosions of nuclear reactors if such had been located in the countries that were seized with civil wars (Lebanon, Yugoslavia, Ethiopia, Rwanda, etc.). The problem of raising security of nuclear power plants becomes more and more topical because of the spread of international terrorism.

Today, 20 years after the accident that shocked the world, a number of problems remain unsolved. First of all, this concerns the problem of the "sarcophagus" – a giant concrete shelter constructed above the destroyed reactor. Corroded by radiation, the sarcophagus may be ruined under the influence of a hurricane or an earthquake shock. There are tens of tons of highly radioactive dust inside the sarcophagus. Each year tons of radioactive waters flow out of it.

If the sarcophagus tumbles down, that will lead to a new considerable emission of radioactivity and pollution of certain regions not only in Ukraine but also in neighboring countries. Therefore, construction of a new shelter above the old sarcophagus became the highest priority.

The issues concerning the health of hundreds thousands of people evacuated from the zone and those who participated in the liquidation of the catastrophe aftermath remain no less topical. The number of victims of the Chornobyl accident is estimated to be tens of thousands of the deceased, although there is no absolute agreement among medical experts as to the precise number of the dead and causes of deaths of many "liquidators".

In conclusion of this short story about certain moments of the Chornobyl catastrophe, I should stress that, by its implications, Chornobyl can be compared to the most devastating wars and invasions of enemies that had serious political, environmental, medical, psychological and cultural consequences.

Chornobyl is a lesson for the humankind for all times which should never be forgotten.

Military liquidators in liquidation of the consequences of Chornobyl NPP accident: myths and realities

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Twenty years have passed after the Chornobyl accident, but its consequences are so immense that even now some facts are still not sufficiently investigated and being a subject for analysis by specialists on radiation protection and emergency response. In this article we will present the available information and our considerations concerning advisability and results of many thousands of military contingents that were involved in liquidation of the Chornobyl NPP accident consequences (LAC).

Some historical information on military involvement into LAC works

Since 1986 the participants of LAC mission were termed “liquidators” in abbreviation form. Then this expression migrated to mass-media and later on to scientific publications. Military liquidators mustered from reserve sometimes are termed “partisans”. Overwhelming majority of liquidators was comprised of such “partisans”.

When the Chornobyl accident happened in 1986, the National (State) system of prevention and response for man-caused emergency situations was not established in USSR [1]. Independently establishments and departments formed response systems for emergency conditions at their best.

Missile Forces of strategic destination and Naval Forces armed by nuclear armaments and defence technology with transport nuclear power units had object and territorial systems of prevention and response for emergency. But these classes of Military Forces (MF) were not involved in liquidation of Chornobyl NPP accident consequences.

In case of a crash of spacecraft with nuclear power unit, a system was planned to be organised on a scale of all MF. 122 mobile detachment of special destination subordinated to Armed Forces General Staff (Headquarters) and extraordinary joint detachments, formed from chemical, radiation and biological defence units in each territorial command and Naval Forces, would be involved in this system.

It was cosidered that MF, including units of Civil Defence (CD), which were subordinated to Ministry of Defence at the time of accident, were technically, organisationally and psychologically ready for operation in conditions of nuclear war. These circumstenses and high mobilisation abilities of MF made themselves involving into emergency works from the first hours after the Chornobyl accident.

In the afternoon of April 26 the first mobile group of Kyiv Civil Defence regiment arrived at the accident site. By the order of Commander of General Staff (Headquarters) of Military Forces, 122 mobile detachment of special destination from the region of Volga River and an extraordinary joint chemical detachment of Kyiv command began to relocate to the ChNPP accident area in the morning of April 27. Those were forces assigned and trained for liquidation of crash consequences of aircraft with nuclear power unit on board.

On April 27 the Air Forces helicopters became to perform reconnaissance flights around ChNPP with the aim of radiation survey and working-off the means for dropping loads into the reactor core. Local (civilian) population together with military personnel of the garrison ‘Chornobyl-2’ that was deployed at 10 kilometers to the south-west from ChNPP long before the catastrophe were involved in loading the helicopters with sand and other materials. Chemical service of this garrison performed in the morning

April 26 (5.00 – 10.30 a.m.) the first radiation survey along the road Chornobyl – Prypyat, inside the city Prypyat, the river harbor, the railstation and around the industrial base of ChNPP and destroyed reactor.

From April 29 the loading of the helicopters were performed by detached battalion of civil defense special protection. Military medical subdivisions provide medical assistance to the population who were evacuated from the 30-km zone from the very beginning.

From the very beginning after the accident, Military units were engaged in implemetation of the most urgent, difficult and dangerous measures on the site. However, later on the governmental leadership began to task irresponsible and absolutely impossible missions of decontamination of the 30-km zone (including Prypyat town) and re-evacuation by early 1987 of the evacuated inhabitants . It caused the commitment of many thousands military contingent to the zone of radioactive contamination. Fig.1 illustrates the dynamics of the cumulative number of military liquidators and the strength of Chornobyl Forces overall the period of MF participation in consequences liquidation.

By the middle of August 1986, the strength of the Chornobyl military contingent amounted to 40 thousand persons. But, considering the unfeasibility of decontamination of settlements located in the 30-km zone, the quick withdrawal of forces from the accident site has begun. By the end of 1986 the number was reduced to a half. During 8 months of 1986, about 100 thousand military took part in LAC.

During 1987, the quantity of soldiers continued to decrease and at the end of the year it was about 13 thousand. The total number of military involved this year mounted to 120 thousands. Next year in 1988, the quantity of Chornobyl contingent went up to 20 thousands and during the year the overall number of liquidators was about 80 thousands.

Mobilisation of large-scale army contingent to LAC was due both to the large scale of tasks posed to MF and predominance of manual labor along with required promptness in liquidation actions. The construction of the protective fence around the 30-km zone was a striking example. This fence of 200 km length was set in 13 days only (from 8.06 till 20.06.86), which involved 7.3 thousand military for hard manual work [3]. But, according to the opinion of specialists, this work could be done by 5 times less military personell if it had been better planned and provided with necessary equipment.

In general, MF were charged withn the following tasks:

- covering of crater of the destroyed power-unit (reactor);

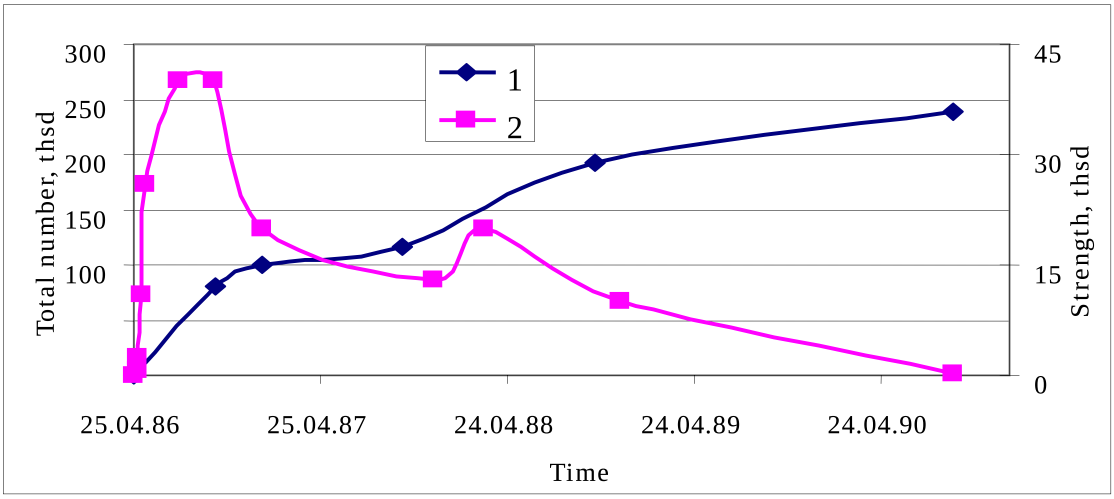

Fig. 1. Dynamics of the total number (cumulative total) of military liquidators (1) and strength of Chornobyl forces (2) during the period of military forces participation in LAC.

- continious radiation survey;
- decontamination of industrial area and NPP premises;
- decontamination of settlements, roads;
- special treatment (decontamination) of the vehicles;
- fencing in the exclusion zone;
- provision of the industrial zone functioning (concrete-mixing plants, communications, loading/unloading works);
- construction of water-protective structures;
- construction of radioactive waste disposal and temporary storage places for debris of destroyed reactor and other radioactive wastes, etc.

According to official data, the total amount of military liquidators during all the period of LAC amounted to 239.3 thousands [2]. Reservists ("partisans") formed the absolute majority, and the number of other personnel amounted to 17 thousands only, including career servicemen and soldiers of service for the fixed period. As a matter of fact, the absolute majority of military liquidators were not military men. They were civilians dressed in military uniform, who were neither physically nor mentally prepared to adequately tackle LAC missions. Some of them, especially in the initial period of LAC works, were deployed in the Chornobyl zone without special training, others were trained for a short time. But neither mustered reservists, nor their trainers could imagine real situation in the Chornobyl zone before being there.

The substantial problem for military subdivisions during the first weeks after the catastrophe was the rapid increase of their number under the condition of constantly changing radiation situation. Consequently, some military units found themselved in areas with gamma-ray dose rate of 50 mRh/h and higher. In search of cleaner areas, some units changed their dislocation up to three times – a major physical and psychological challenge for the servicemen in addition to their unjustified exposure to radiation.

The % fraction of the strength of different branches and provision units of Chornobyl forces is presented in Table 1.

Table 1.
The % fraction of the strength of different branches and provision units of Chornobyl forces.

Subdivisions of MF branches and provision units in Chornobyl forces	Proportion, %
Chemical	40 – 44
Engineers	28 – 32
Civil defence	6 – 8
Rear forces	6 - 10
Technical provision	7 - 9
Administration and others	4 - 6

Arrangements for military liquidators dose control.

Already since the first days following the Chernobyl NPP accident, it became evident, that MD Order № 285 dated 08.12.1983 [4] merely outlines a system of radiological protection of military men and dosimetric monitoring in case of radiation emergencies. For such a system to function effectively, dozens of regulatory and guidance documents had to be prepared and a wide range of arrangements made.

The unprecedented scale of the Chernobyl Disaster, difficulties in forecasting the scope of work to mitigate its consequences were the main reason for a debate within General Staff between the Military

Medicine Service Command, who insisted on setting peacetime norms (25 rem), and the Head of the Radiation, Chemical Biological Protection Department, who proposed wartime personnel exposure norms (50 rem) as the basis [2, 5].

However, even with such an uncertainty in exposure limits in the first post-accident days, Radiological Protection Service (RPS) and Dosimetric Monitoring (DM) within the LAC units did function. Thus, the KMD Air Force Commander – 1 May 1986 [6], and later on the KMD Commander– 4 May 1986 [7] issue orders on RPS arrangements in the subordinate military units involved in LAC. These orders establish exposure limits for military servicemen throughout LAC: 24 rem for Air Force servicemen and 25 rem for the rest of military liquidators.

Therefore, RPS including DM, was organized within all units arriving at the wrecked ChNPP area and getting under command by the KMD Force Commander already since the first days of their stay in the accident area. It is primarily indicated by the high level of provision of military liquidators with dosimetric monitoring data during that period in the State Chernobyl Registry [8].

It is worth mentioning, however, that the first post-accident activities of the military radiological protection services did not catch up with the situation as it developed, and regulatory requirements were not fully met. Particularly, already as of 1 May 1986 (issue date of the KMD Air Force Commander Order), the strength of units involved in the accident area activities almost reached 600 persons, including up to 100 representatives of KMD Air Force units, and as of 4 May (issue date of the KMD Commander Order) it was already a multi-thousand military contingent that participated in the emergency activities. In violation of i. 35 of MD Order № 285 dated 08.12.1983 [4] personnel were involved in ACL without orders authorizing work under high exposure doses, the first order of this kind was only issued on 1 May.

The permissible dose limit debate lingered until 21 May 1986. The normative uncertainty with respect to external exposure doses resulted during the first post-accident weeks in the exposure of 52 servicemen of Special-Purpose Chemical Force Unit 122 directly subordinated to Department Head of the RCB Protection Force, to doses of up to 72 rem [2, 9]. Meanwhile, the personnel of the military units subordinated to KMD, who carried out radiation reconnaissance missions of comparable radiological hazard or even more hazardous ones (flights over the wrecked unit), were exposed to much lower doses (Table 2). This Table demonstrates a dependence of the average military liquidator dose during the first month of liquidation activities on the set dose limits.

Table 2.

Doses of radiation to military units staff members participated in LAC in April-May 1986

№	Units	Sample size, persons	Dose limits, Rem	Confines of dose intervals, Rem		Average dose, Rem
				Min	max	
1	Chemical Force Unit 122	38	50	40	72	54.2±1.3
2	KMD Consolidated Chemical Unit	25	25	25	30.9	26.7±0.2
3	KMD Air Force	31	24	13.5	29	21.6±0.4

The permissible dose limit uncertainty was ended by MD Order №110 dated 21 May 1986 [10], which set the dose limit for all military servicemen at 25 rem. Item 3 of this Order provides for using “group” and estimated “group” dose assessment methods along with individual dosimetry. In addition, the permissible daily dose of 2 R [11] is introduced to prevent mass exposure of liquidators to major doses in the accident area. This measure made it virtually impossible to use common military dosimetry equipment to monitor exposure doses of military liquidators (Table 3).

Table 3.

Precise characteristics of domestic common military dosimetry equipment

№ за/п	Type	Range of measurement	Possibility of automated reading of data
Means of military dosimetric control			
1	ИД – I (ID-I)	20 - 500 rem	absent
2	ДКП - 50 А (DKP-50A)	2 - 50 R	absent
Means of individual dosimetric control			
3	ДК - 0,2 (DK-0.2)	10 - 200 mR	absent
4	ИД- II (ID-II)	10 – 1500 rem	absent
5	ДП - 70 М (DP-70M)	50 - 800 R	absent

In addition, another 30 various regulatory and guidance documents were developed [12, 13, 14], which detailed specific provisions for radiological protection of military liquidators.

In spite of all instructions for implementation of individual dosymetric control in liquidators units with the use of individual dosimeters, such kind of control was not implemented. Thus the group method (one individual dosimeter in a group) and group-calculated method (dose evaluation is made for military group taking in account the dose rate of gamma-ray at the working place and working hours) prevailed in Chornobyl forces. According to of some authors [15] the errors of these methods were 250% and 500%, respectively.

The execution of decontamination of the Unit #3 roof in the period from 19.09 till 2.10.1986 could be the only exception. In these works, besides the calculation method, the obligatory operational control of radiation dose for participants was put into practice using dosimeter ДКП-50 А (DKP-50A) [16, 17]. In total 3,026 militaries took part in this work. I.e., taking into account that the total number of military liquidators amount to about 300 thousands, we should conclude that only about 1% of liquidators were really provided with instrumental dosimetric control, but not 14% as was mentioned by V.V.Chumak [8].

It should be noted, however, that the organization of ChNPP Unit 3 decontamination work also gave an example of failing to meet the Order-established norms: in defiance of all the then existing orders, the one time exposure dose limit of 20 rem was established for participants of ChNPP Unit 3 decontamination work by the Guidance For Work Organization And Performance [18], which was not introduced by any order. And because military man were involved, who had already been exposed to some doses, in certain cases the total dose exceeded 25 rem.

Another attempt to organise the day-to-day dosimetric control of almost all military liquidators using dosimeter ДПГ-03 (DPG-03) was made at the end of 1989 –beginning of 1990, and also failed.

The liquidator contingent with reliable doses can not be expanded by individuals from groups where doses were monitored by the «group» method, since servicemen who wore ID were constantly replaced. Therefore, total individual exposure doses for military liquidators, identified based on individual dosimeters are virtually missing.

It should also be borne in mind that the estimated “group” dose assessment would normally use the military roentgenometer-radiometer DP-5, while the “group” assessment method– the DP-50A dosimeter. Both devices were calibrated in Roentgens, accordingly, the records in the ACL military unit exposure logs were also made in Roentgens. However, when filling out Registry questionnaires, instead of Roentgens, the same value but in rem was entered automatically, without factoring in the conversion rate of 0.67–0.71, which also contributed to overestimating the official dose records (ODR).

Therefore, on the one hand, military liquidators are best provided with official dose records [8], while on the other hand – there are serious doubts about the quality of those dose values because of the predominance of the "group" and estimated "group" methods of their assessment. A major effort to verify those doses would be needed if we were to use the data on the exposure of military men in epidemiological studies [8, 15].

Veryfication of radiation doses to military liquidators

The first stage of verification addresses the objectivity issue of dosimetric monitoring. A whole series of verification methods to deal with available dosimetry information has been proposed, the predominant majority of which are based on variation statistical methods.

Due to monitoring of the doses with near-permissible values, the distribution of doses around the boundary value becomes normal. The so-called hybrid lognormal distribution (combination of logarhithmically normal and normal distribution) gives a good reflection of data observed in many of such cases [18].

The attempts to clarify the dosimetric monitoring objectivity situation in the LAC Units that we know of were made based on a statistical analysis of too generalized information [15, 19], or using insufficiently accurate database of the All-Army Registry [20] without considering the organization specifics of service, work and dosimetric monitoring in those units.

The irregular distribution of military liquidator exposure doses, being generally limited within a range of 10–25 rem, led some authors to conclude that the main source of distorted dosimetry information in Chornobyl Registrys are the relevant Services of MD units [15, 19]. These authors believe that the range of activities performed by MD units was very wide and only a portion of it was related to exposure to significant individual doses. In other words, a wide range of tasks to deal with must correspond to a wide enough and smooth distribution of individual doses.

To clarify this issue, we have analyzed the military liquidator exposure doses for various LAC activities, which differed in principle by nature of activity and health conditions. The outcome of this analysis for May 1986 - May 1987 is given in Table 4 and Figures 2–6.

Table 4.

Average radiation doses to personnel of different units

№	Name of the unit and branch	Sample size, persons	Region of operation	Work character	Average dose, cSv
1.	Detached Mechanised Regiment (DMR) of Civil Defence	4704	ChNPP	Decontamination	22,57±0,10
2.	Military Construction Battalion (MCB), sappers	3489	ChNPP, 10-km zone	Decontamination, construction	20,02±0,08
3.	Gas Defence Brigade (GDB), Chemical Forces	2465	ChNPP, 10-km and 30-km zones	Decontamination	20,08±0,15
4.	Rear and technical provision units	2158	30-km zone and outside it	Rear technical provision	7,82±0,91
5.	817 Operational Group (OG), management body	1164	30-km zone	Management	9,23±0,60

The Table 4 data indicate that the average military liquidator exposure doses are determined by the area and nature of LAC activities performed. Specifically, the average doses are much lower for units that did not performed work directly at the ChNPP industrial site. Maximum doses are observed in CD, chemical and engineering units; much lower ones in administrative units; and minimum ones in logistics units.

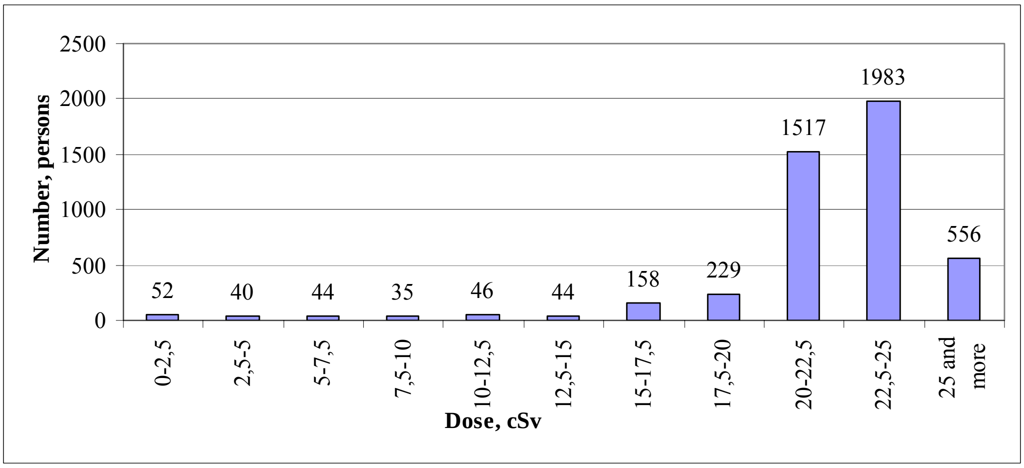

Fig. 2. Distribution of radiation doses to military personnel of detached mechanised regiment in period since May 1986 to May 1987 (n=4704).

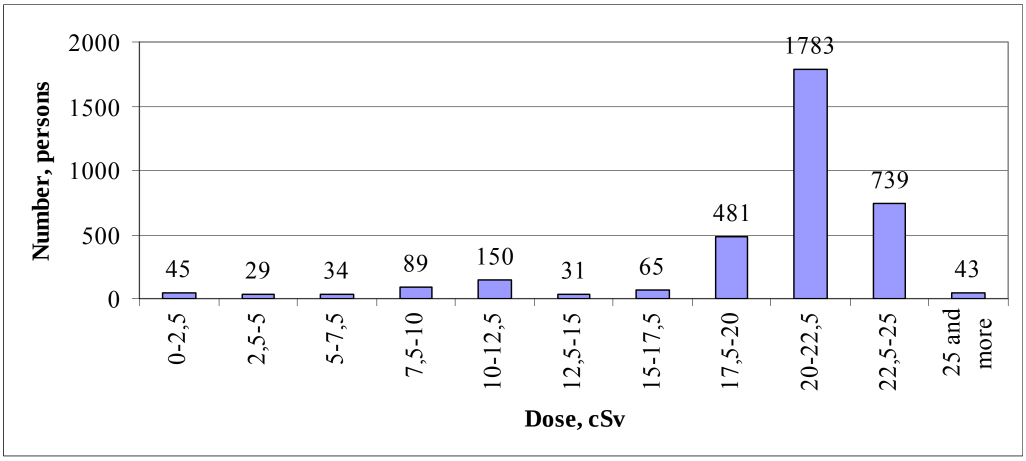

Fig. 3. Distribution of radiation doses to personnel of military building battalion in period since May 1986 to May 1987 (n=3489).

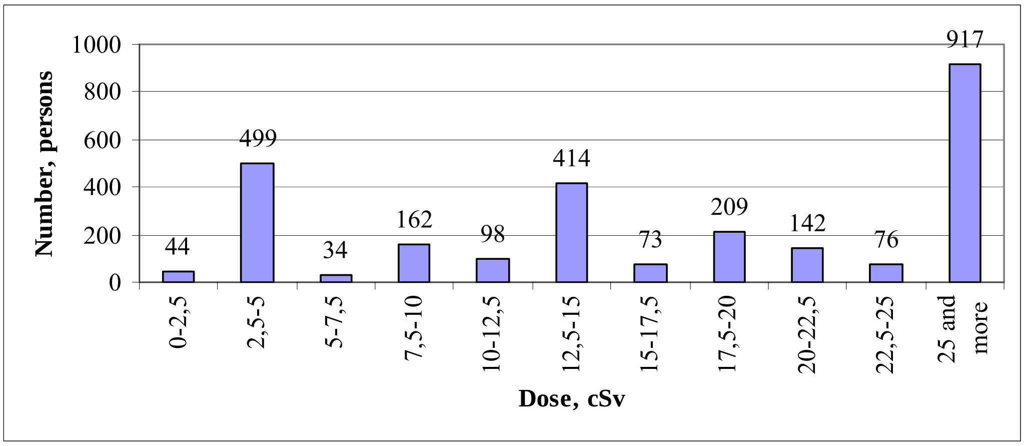

Fig. 4. Distribution of radiation doses to military personnel of 25 gas defence brigade in period since May 1986 to May 1987 (n=2465).

Accordingly, the exposure dose values for SMR and MEB, which worked under the most radiologically hazardous conditions, are skewed towards the permissible dose limit of 25 cSv (Fig. 2, 3). Because various CPB units were both onsite at ChNPP and at various distances from it, the exposure dose distribution for this part of liquidators has a somewhat different nature, but most doses still are placed around 25 cSv (Fig. 4).

In the opinion of some authors [8], that we share, such an irregular distribution of doses for CD, chemical and engineering units resulted from a stringent dose management rather than total falsification. Therefore, the major doubts held by some authors as to objectivity of dosimetric monitoring in LAC units are primarily due to these researchers' insufficient awareness of the organization of dosimetric monitoring and activities of this liquidator contingent. Yet one cannot totally dismiss facts of dose falsification, nor the possibility of unmonitored exposure of a certain part of liquidators to doses significantly exceeding the permissible ones [9].

It should be taken into account that a monetary compensation adding up to 5 monthly remuneration rates was provided for exposure to a dose of 25 cSv and above. In other words, there was a significant material "interest" in receiving a dose of 25 cSv and higher. Once the dose limit was set at 10

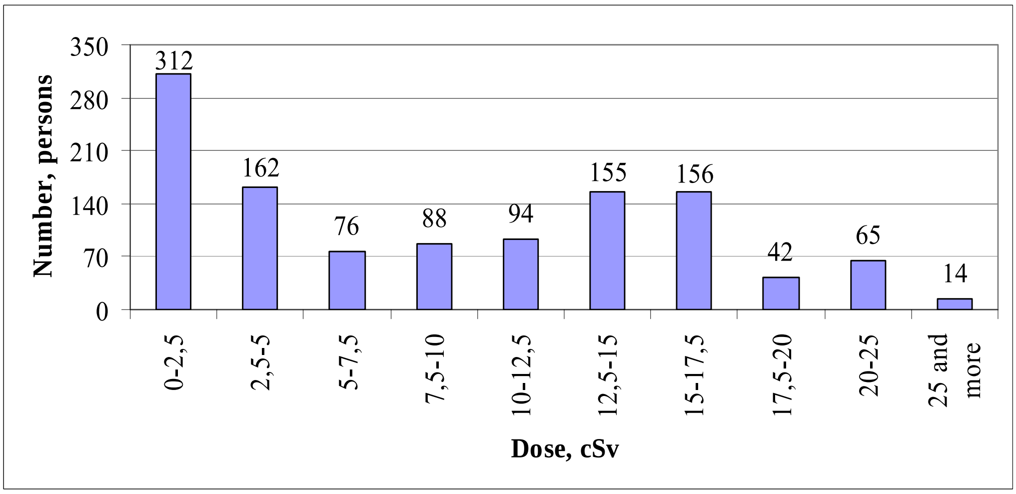

Fig.5. Distribution of radiation doses to military personnel of 817 OG in period since May 1986 to May 1987 (n=1164).

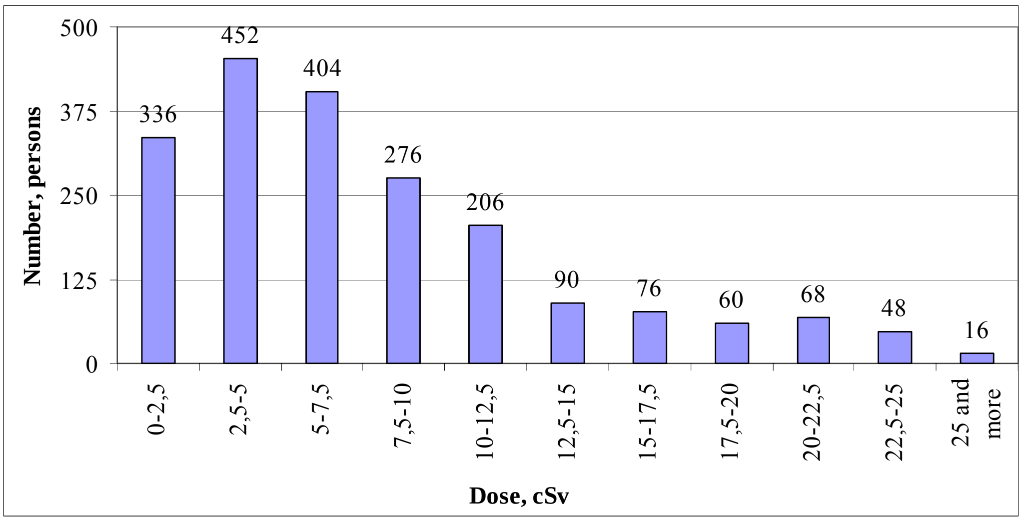

Fig. 6. Distribution of radiation doses to military personnel of rear and technical provision units in period since 22.06.1986 to 08.08.1987 (n=2158).

cSv, cases of reaching the dose limit became singular, and cases of exceeding 10 cSv went virtually unrecorded, which can support our assumption. It should be noted, however, that cases of modifying exposure doses for social reasons had place among liquidators from other ministries and agencies [8].

For OG 817 and especially for the logistic units that worked under more favorable conditions in terms of radiation exposure than the aforementioned ACL units, the exposure dose distribution is close to logarithmically normal (Fig. 5, 6).

Therefore, the exposure dose value and the nature of dose distribution in military liquidators are generally consistent with the nature of LAC activities and exposure conditions. But, in general summaries the dose distribution specifics in serviceman of LAC units, which worked under safer radiological conditions, is offset by the data on exposure doses in the more numerous CD, chemical and engineering forces.

Another step in dose verification is to establish a ratio between officially recorded (obtained via the "group" and estimated "group" methods) and specific reference military liquidator exposure doses, which objectively reflect the real situation.

As reference ones, we will use 2,447 records for military liquidator exposure doses measured with thermoluminescent dosimeters, courtesy of the archives of Kombinat Production Association (eventually transformed into RPA Prypyat).

Based on these data we have calculated the average doses received by servicemen for two weeks (basic term of wearing a dosimeter), total exposure doses were calculated for 12 weeks – a duration of military liquidator stay in the ChNPP area that is also a conservative enough assumption.

A comparison of doses calculated based on measurement and official dose records (ODR) in the same contingents is shown on Table 5. The Table 5 data indicate that ODR exceed the doses obtained through individual dosimeters, by an excess of 4.5 times in1988 and more than twice – in 1989 and 1990.

Table 5.

The ratio between calculated and measured by individual TLD doses for military liquidators

№ з/п	Year	Average dose obtained by estimation method, cSv/number of persons in group	Average dose measured by individual ers DPG-03, cSv/number of persons in group dosimet.		Ratio between estimated and measured exposure doses
			For 2 weeks	For 3 months	
1	1988	5.56 ± 0.97/7502	0.2± 0.05/68	1.2	4.63
2	1989	3.12 ± 0.12/5862	0.22±0.03/568	1.32	2.36
3	1990	4.94 ± 0.22/2748	0.36±0.03/1811	2.16	2.29

Also noteworthy is the ratio between projected (estimated) and actually measured with ID of the RMP 50A type exposure doses of the military men who decontaminated the ChNPP Unit 3 roof. Table 6 provides literature [17, 20] and archive data on the exposure doses of this contingent. Again we see that the projected (estimated) dose in average is twice that actually obtained.

When analyzing other archive materials, we found evidences of dose overstating aimed on pre-term exemption from military training [22], as well as methodic problems of different kind [23, 24]. By the way, cases in which the group method gave precise values were quite rare, and dosimeters Д-2Р (D-2R, desined for use in nuclear industry, being a kind of ionisation chamber) used in this method in the conditions of hard beta-radiation overstated the dose no less than twice.

I.e. the analysis of radiation doses of large contingents of military liquidators showed that ODR no less than twice overstated the really received radiation doses.

Table 6.

The ratio between calculated and measured by individual dosimeters doses for military liquidators participated in decontamination works on the roof of Power Unit #3.

№	Date of work	Number of liquidators, persons	Average dose by calculation method, R	Average dose by individual dosimeter meterage, R	Ratio
1	28.07.86	8	1	0.4	2.5
2	19-20.09.86	133	20	8.5	2.35
3	21.09.86	307	20	10	2.0
4	22-23.09.86	953	20	9	2.22
5	24.09.86	376	20	10.6	1.89
6	26.09.86	270	20	13	1.54
7	27.09.86	300	20	16.2	1.23
8	14.10.86	30	20	8.26	2.42
9	15.10.86	16	20	9.9	2.02
10	16.10.86	28	20	10.29	1.84
	Total	2421			2.07

Morbid and mortal events of military liquidators during performance of LAC works

The data on pre-term dismissal of military servants of SMR and CPB units for the reason of health problems are presented in Table 7. First of all, it should be mentioned that these data are not fully consistent with the realities and are insufficient for well-grounded conclusions. In particular, it is unlikely that the aforementioned units should have had more cases of dismissals for health considerations in 1987 than in 1986. Yet these data are quite enough to state that in a predominant majority of liquidators dismissed for health considerations, their exposure doses and duration of stay in the accident area were significantly less than in their colleagues who had no health concerns.

In a predominant majority of liquidators exposure doses were at the level where they had just some likelihood of physiological deviations unrelated to health dysfunctions. The opinion that radiological factors made a very insignificant contribution to deterioration of liquidators' health can be attested by the fact that two out of three liquidators deceased were recorded on the third and fifth day of their stay in the wrecked ChNPP area, and the duration of stay of the third deceased was also within average for their unit. The main cause of death in all these cases was acute cardiovascular deficiency.

In some orders issued by military unit commanders we find records on other lethal cases among liquidators, but no summary information available on this issue. Therefore, we can provide but very rough estimates of total lethality by extrapolating the ratio of the number of SMR serviceman and number of deaths among them onto the total number of liquidators. Since the total number of persons who served in SMR in January – June 1987 was about 2–3 thousands, then the total death-toll for the contingent of 300 thousands could have been about 300–450 cases.

The Chornobyl Military Force Commander Order № 5 dated 29 January 1990 [26] indicates that in a majority of military units no in-depth medical examinations are conducted, resulting in cases of late diagnostics of ailments, up to lethal ones (private K. – shower & laundry detachment, praporshchik D. – military trade unit 960, private S. – military detachment 63279 etc.). And that happened in 1990, when the military liquidator exposure dose did not exceed 5 rem.

Table 7

Dismissals, exposure doses and duration of stay in the accident area for servicemen of SMR and CPB during 1.05.1986 through 31.12.1987

Year	Work period	Exposure dose, cSv		Average duration of periods of staying in Chornobyl zone		Number of liquidators dismissed for health considerations	
		DMR	GDB	DMR	GDB	DMR	GDB
1986	April- May	23.23±0.2	18.4±0.4	28.9±0.6	21.6±0.8	- ???	1*(7)/(25)
	June-August	22.17±0.4	14.3±0.6	55.7±0.5	29.3±0.4	1	1*(36)/(2.5) 1*(28)/(14)
	September-December	23.1±0.2	24.3±0.3	57.3±0.3	41.7±2.2	1	-
1987	January-June	22.1±0.19	18.1±0.5	69.6±0.7	69.1±1.9	**1**(53)** **1**(3)** **1**(5)** 1*(53)	-
	July-December	10.7±0.28	9.3±0.2	72.1±1.2.	54.1±1.5	1*(20) 1*(21)	1*(39)/(4.8) 1*(51)/(7.02) 1*(30)/(0.2) 1*(49)/(6.0) 1*(47)/(4.3) 1*(39)/(8.8) 1*(71)/(3.7) 1*(35)/(5.5) 1*(44)/(9.1) 1*(35)/(5.7) 1*(69)/(8.9)
Total during 1986 and 1987						10	14

* in parenthesis duration of period of staying, days (numerator) and radiation dose, cSv (denominator);

** liquidators died in Chornobyl zone, in parenthesis duration of period of staying in the zone.

Researchers of the morbidity problem detected no essential connection between availability of liquidator complaints and duration of their stay in the accident area, as well as the location and nature of recovery activities [27]. The Table 8 data can also confirm that it was other factors rather than the radiological one that was the cause of liquidator health condition deterioration.

Table 8.

Dismissals and exposure doses for military liquidators of the first and third sectors during 20.12.1986 through 30.03.1987

№	Subordination	Period	Number of dismissed for health considerations	Average dose for dismissals for health considerations, cSv	Average dose for liquidators in 1986–1987, cSv
1	Sector 1 (Blorussian Command)	20.12.86-16.03.87	84	2.39±0.13	5.7±0.3
2	Sector 3 (Prycarpathian Command)	03.01.87-30.03.87	23	9.57±1.29	15.17±2.3

The exposure doses for military liquidators of the first and third sectors who were dismissed for health considerations did not exceed the average for the whole sectors and those levels that could theoretically cause changes in their health condition.

In our opinion, the sudden conscription with a drastic change of habitual living and working conditions, frequent relocations in the accident area provoked a major strain of adaptive mechanisms and transition of certain body parts and systems, primarily the cardiovascular one, to a critical functioning mode. It was what induced the aggravation of chronic diseases and sometimes – emergence of critical conditions and lethal cases. The radiation factor is seen from the exposure doses available to have been one of the least significant one.

As a results of a large number of liquidators dismissed for health considerations, people developed a belief that recovery work at ChNPP was extremely dangerous, hence the liquidator contingent grew, which intensified the psycho-social consequences of the accident.

Conclusions

1. The State's unpreparedness for action in emergencies; charging the Armed Forces with unfeasible tasks; predominance of manual labour in LAC; use of DM methods that overestimated dose by about twice; imperfect system of medical selection of reservists drafted for a training assembly for LAC, –that altogether unreasonably enlarged the liquidator contingent, increased LAC costs and intensified the socio-psychological consequences of the Chernobyl Disaster.

2. The system of radiation safety and security of the Chernobyl Military Force, whatever its shortcomings may have been, has prevented military servicemen from being massively exposed to doses capable of inflicting radiation injuries.

3. The exposure doses and duration of stay in the accident area of military liquidators who were dismissed for health considerations or died during their stay in the accident area were notably lower and shorter than average for the unit where they served.

4. Scientific attention should be paid also to the influence of non-radiation factors (such as stress etc.) on the health state of military liquidators during their recovery works and in long-term aspects.

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My Good Life in Pripyat, the Disaster Caused by Chernobyl, and the Catastrophe of the Nuclear Power Station and of Our Lives

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I would like to begin my story by writing about the beautiful natural setting of the land where I was born. My village is called Leskonope. Its houses are small and lie hidden in the dense green of its many trees. It is located on a hill and from its highest point there is a beautiful view of the river, a branch of River Desna, that flows nearby, with thick tall rushes and woods on each bank. However often I visit my birthplace, I am never tired of its beauty. My heart beats more quickly at this magnificent view. For me, nowhere is as beautiful as this place with its vast meadows, its forests and the fast-flowing Desna.

At the village school I attended, I was taught to love nature, to respect my elders, to study hard, to do my best to earn better grades, and to love hard work. For these lessons, I will always be grateful to my first teachers. Looking back on my childhood, I remember how proudly I used to sing at village concerts. Students from my school participated in the concerts the village held on every festive occasion. After finishing the eighth grade, I continued on to the ninth and tenth grades at Ushinsky Boarding School in the same district. At the center of this ancient region is Novgorod-Seversky, from which, as the histories of long ago record, Prince Igor Svyatoslavich departed on his punitive expeditions against the Polovtsians. I studied hard at school and participated in extra-curricular activities. I loved to sing and always dreamed of continuing on to sing before audiences.

When I finished the tenth grade, I took the university entrance examinations. I went to a preparatory course at night and worked as an electric panel controller at the steel mill in a machinery factory in Kostroma during the day. However, when I was unable to enter the department of engineering at the university, I returned home. At that time one of my relatives was home from Pripyat and he suggested I get a job in that town. He praised the place where he lived, telling me that it was a town of young people and that I would come to love everything there.

That autumn I went to see him in Pripyat. With his help, within a month I found work planting trees for the town. I have never been afraid of hard work. I lived in a dormitory at work. How I loved this small, quiet town of Pripyat where most of the residents were young people. It was as if my youth spread its wings and took flight. This was the happiest time of my life.

I often think of the time when I was young and had just arrived in Pripyat to start working. I made many new friends in the dormitory. One of them was an acquaintance of the leader of a music ensemble of young working people. Most of the members of this ensemble were five or seven years older than I, and some were already married. That did not matter as long as they shared the same interest in music. After work they gathered and practiced in a music room, which was in the men's dormitory and was where all the instruments were stored. There were such instruments as drums, cymbals, a bass guitar, a rhythm guitar, a lead guitar, an electronic organ, a saxophone, a trumpet and an electronic bayan. The ensemble's leader Stanislav Ivanovich was responsible for all of the instruments.

One day when my new friend heard me singing, she suggested I should go to see Stanislav Ivanovich. So one evening we went to the music room to see him. He asked me to sing something and he liked my voice very much. This was how I made more new friends and began to sing in this music ensemble. Singing with accompaniment, I thought my modest dream had come true. How happy I was every day rushing to rehearsals to practice new songs and talk with friends after work!

During the summer, concerts were held in front of the Pripyat Culture Center on holidays.

Many groups like our ensemble performed on these occasions. These days in 1981 and 1982 were truly filled with joy. We often played for the nuclear power plant construction workers. At first I had inexplicable fear in front of that audience but later I became more courageous. Such cheerful and carefree days flew by so quickly. How beautiful were the summer nights in our town, with the sweet fragrance of white peonies and Chinese roses growing near the culture center. Around the town there were many beds of roses whose scent always reminded me of the river near my home with its white water lilies. The smell of these splendid flowers somehow resembled each other. There were pine trees beside the bus terminal I used to walk through the woods to work. These woods also reminded me of my home village.

The air in our town was very clean! The many pine trees filled it with much oxygen. We frequently played and sang at Lazurny, where every year the power plant workers celebrated the anniversary of the start of operations at the nuclear power station. So my youth flew by quickly with work and singing practice. After working for the tree planting project for a while, I got a job at the 'Jupiter' Radio Factory. This was a subsidiary company of the 'Mayak' Radio Factory in Kiev. I was employed as an apprentice lathe operator in the mechanical press section. Most of girls working in the same team were between seventeen and twenty-five, and there were only four over thirty-five. I began work on a machine with only two functions. Within a month I was already working on a semi-automatic lathe with 16 functions, grinding side units of the 'Jupiter' tape recorder. This work was very hard. We had to grind 600 units per shift. When I was working the first shift, I used to run to the music room to see all my friends after work. When I was on the second shift, I did not see them for a whole week. One day my friend told me that a knitting course was open to us. I wanted to learn machine knitting, and so I began to attend the course before I set off to work the second shift. I learned the basic usage of knitting machines and I liked it very much.

It was time that girls of our group of young lathe operators should be married. At one of these weddings held at Chistagolovka, a village five kilometers away from Pripyat, I met my future husband, Viktor. Later I heard from his grandmother that he immediately fell in love with me and told her that he would be the happiest man in the world if I would marry him. Two years would pass after that first meeting before we met again. During that time, I completed the crane operators' course, which was attended by mostly only young people.

Passing the examination, we obtained certificates that allowed us to operate both gantry and tower cranes. It was time to find a job as a crane operator. I remember that I was so scared to climb up on a crane for the first time that I almost had to be driven up there with a willow switch. With great effort, I got into the cabin but getting down from it was another big task for me. I had to fight and overcome my fear of heights. I continued to sing with the ensemble as before. We began to perform at weddings on the side. I sang and the others played instruments. It was so nice to perform in front of happy young couples with their eyes shining and full of love.

I decided to look for work as a tower crane operator. I visited the crane section of a construction office and they told me that they had hired a crane operator only a few days before. I told this to my friend in the ensemble. She calmed me down by telling me that she would immediately telephone a mechanic in the crane section who would help me. Her telephone call in fact gave me a lot of hope. I took the bus to once again visit the head office of maintenance of the crane section. This time I was hired as a substitute crane operator.

The next day, I went to my new work and was given instructions on technical safety. And that morning I met my future husband for the first time in two years. He greeted me first and then asked whether I had attended the wedding at Chistogolovka. I answered yes. Gazing at something on his desk, he then asked if I had a picture taken at the wedding. I had no memory of a photo with anyone at the wedding but I was actually in a photo with other girls and beside me was Victor. It was only in spring 2000 that my husband brought that photo back from Chernobyl. I had never seen it before because he had always kept it with him at work.

This was our second meeting. I began to work in the same section where Victor had been already working as a mechanic. He had a good relationship with his boss in the construction division. Victor's approach to me was quite elegant. But I was a very serious girl even tough I had more male friends than female ones. I worked as a substitute, learning how to operate all kinds of gantry cranes at the loading and unloading area and then tower cranes at the second and the third construction sites of the nuclear power station. How I liked this work, up on a crane where I could see everything. For me going to work was like going to a festival, and with such joy I went to my job as a substitute crane operator. My effort and sense of responsibility gained me the respect of the assemblers I worked with. I was proud of working at the nuclear power station and living in this city surrounded by green and filled with young people. I continued to sing with my friends in the ensemble. I loved music and I loved to sing.

Victor and I had been very good friends for a whole year and in spring 1984 we decided to get married on July 14. At the end of September, Victor was offered a one-room flat for a small family, with one big room, a kitchen, a closet, a balcony and a toilet with bath. It was splendid for us. We left Victor's parents' house, though their village was only five kilometers away from Pripyat, and we started to live on our own. I stopped singing when I got married. Soon our first son Yuri was born. He was a sickly child, and often suffered from colds and tonsillitis. When I was on parental leave to look after him, I was always curious to know how it was going at the construction site: which cranes were they using and how high were the walls they were building? I was very interested in any news I could get about construction progress.

And so the spring of 1986 arrived. By that time, Yura (our nickname for Yuri) could walk a little if we took his hands, and we often visited Victor's parents with him in a buggy. Victor's youngest brother was about to depart for military service. We went to the parents' house a day before his farewell party and helped to prepare for it. That evening many relatives and friends gathered and the party continued until the next morning. Yuri and I were outside. Friends and relatives drove Nicolai to the national service command just after five o'clock in the morning. At seven o'clock people in the village started to talk about an explosion at the nuclear power station. Although I could not believe the news, I was anxious waiting for the car to come back from the Chernobyl national service command. Many little children besides my son were left waiting with me. The car had to take a roundabout way through the forest to come back, as roads were closed down everywhere. It was true that there had been an explosion at the plant. But we continued to clear the tables and wash the dishes.

At three o'clock in the afternoon, Victor's sister's husband, a police officer, arrived. He said he had come to evacuate us. The wind was blowing towards the village and thus the amount of radiation was increasing. We got into the car and decided to go towards the nuclear power plant, but we stopped at a restaurant called Evrika. My husband said it was better for us not to go any farther with a child, and we turned the car around. We saw flames burning under the smokestack of the power plant. It was only because Kolya was a police officer that we could reach that point at all. So we became witnesses of the nuclear power plant accident, without understanding all the seriousness of the disaster that had happened. We went up on the roof of our apartment and through binoculars we watched the flames of the plant until late that night. That night we received iodine treatment and were told to close the windows. Nevertheless we did not understand sufficiently what all had happened.

The next day, on Sunday, the evacuation started. We were told to take only the things necessary for three days. Yura and I went to my parents' and Victor stayed at home in Pripyat. Victor's parents stayed in the village until May 9th and then they were evacuated to a village in Borodyansky district. I well remember the day of the evacuation and how we went through villages and the city of Pripyat in a bus. We saw people standing on roadsides whose eyes were telling us, "you are going and we are staying."

When we arrived at my home village, there were six other mothers with children like me. Their husbands had stayed behind to join in the clean up after the accident. Our clothes and shoes were examined to check the amount of radiation. The radioactivity detector made sounds. Our clothes were confiscated and we were given new clothes and shoes to wear. Victor stood guard duty against an invisible enemy who could not be heard or seen. He came to the village to my parents after finishing his shift. He told me that a cold sweat ran down his back as he rode in an armored car with young soldiers through the forest that had taken on an orange color, and that he was sorry for those young soldiers who had just begun their duty and their lives were brought to clean up after the accident.

When my husband came to us in June, he took me and Yuri to Chernikov for Yuri to have an operation – he was suffering from an acute hernia. Victor drove us to Chernikov early in the morning and then he returned to his duty. Two weeks later, after Yuri was already out from the hospital, Victor visited us again.

A new place to live was provided to us in the middle of August but my son and I did not move in until the 21st of September. We gradually bought some furniture with the compensation money we had been paid then. We were now in Kiev and I thought there was no way we could get used to this big and noisy city. We missed Pripyat and still do to this day. What a small and peaceful town was our beloved Pripyat! We could walk all round the town in just a short time.

As time passed, Yuri was growing up. My husband continued to work as a watchman and soon he became the chief watchman. I pleaded with him not to go to work in the contaminated area but to stay with us. Yet his answer was, “Can you imagine not being able to go back to your hometown?” However, his hometown had already been turned into a wasteland with only one shop, a war memorial, and a single house left at the edge of the village.

When big holes were dug and the houses in the village were all buried, Victor asked the white birch growing by the well be left to mark where his house used to stand. Victor always visited his village whenever he was on watch. He loved it so.

My health declined with time. I began to suffer severe headaches and very frequently felt something wrong with my heart. In five years, two more babies, Vovochka and Maryka, were born and Yuri turned 5 years old. They were not very strong children and I stayed home with them. Victor’s health was also clearly unstable but he never wanted to listen to us telling him to quit his job in Chernobyl. I begged him to be treated in the hospital, but he was somehow scared to go. One day he told me that when he goes to the hospital it means he is dying. None of my attempts to persuade him had any effect. He was always telling himself that he would not die until our daughter got married. I myself often had to call the ambulance, and, when Victor was away in Kiev, I would enter the hospital for treatment.

He continued to work at Chernobyl. In 1995 there was a large amount of salary that was owed to the people working at Chernobyl. Workers organized a strike and those who went on a strike were paid, but what my husband received was very small. We could barely survive with the help of my parents. The amount of unpaid salary kept increasing until 2000. My husband did not quit his job only because he had hopes of receiving what he was owed. Even now, however, we have yet to be paid this money.

At the end of 2000 my husband’s condition went terribly bad---he could not sleep or lie down, but could only stand and walk. Once when he was feeling very hard he said to me, “Tamara, I have not had a single day off for seven years.” Nevertheless, he did not go to hospital. He was scared. In November he took time off to rest at home. December passed and at the end of January he at last went to hospital and had an X-ray taken. Doctors said that he was suffering from tuberculosis, but I never believed them. Later I was proven right. He did not cough at all. Instead he had a severe backache. It was as though an iron hoop were squeezing his chest. He abruptly lost weight. The results of the examinations were bad, but nothing was made clear by ultrasound.

At the hospital in Solomenka district, a professor told me after administering an ultrasound

Younger son, Vova. He died in 2001.

Daughter, Maria and elder son, Yuri. 2004.

examination that my husband had pancreatic cancer. It was as if the ground collapsed under my feet and I felt like I lost my consciousness for a moment. I did not want to believe the doctor's words. I prayed day and night believing that a miracle would happen after all. With all my might, I tried not to cry in front of my husband but on the way home I could not stop tears from flowing. At home I also held back in front of my children. I prayed to God and begged for help. Before going into the operation, Victor wept and I assured him that everything would be all right. That night he was moved to surgery from the intensive care unit. Hope for life seemed to light up in his eyes. On the second day, Friday, he was again moved to the intensive care unit and the light of his hope was snuffed out. Ten days after the operation, he passed away.

However reluctant I was to go on living, I had to bring up and educate my three children. Still I felt that life without Victor was meaningless. I cried and my medical condition was aggravated. I had had medical treatment but did not get well. When I lost my younger son, three years after my husband's death, I thought I would go mad. It was the second time and I was saying to myself "why my son and not me?" Two children were left. Even though I knew that they needed me, I could only walk like a robot for a whole year. How hard it is to live with such wounds, unable to breathe deeply or to stand up straight, unable to do anything with such a burden on my shoulders. I am always afraid about how I can go on living.

I am very grateful to the kind Japanese people who support us by sending money and medicines. Medicines are essential for us but doctors cannot prescribe expensive medicines at no cost. It is impossible to buy expensive medicine for my children and myself even when they are ill. Dear friends, may be God with you and protect your families from misfortune and grief. I thank you for your kindness. May the same kind of accident that happened here never happen anywhere else. I would like to finish my story of why I came to live in Pripyat and how we live in Kiev now. May all people of the world be blessed with happiness and love.

(Translated into English by HASEGAWA Kaoru)

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Discrepancy between the Contamination Pattern and the Daily Radiation Survey Data Used for External Dose Estimation of Evacuees from the 30-km Zone

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Introduction

A series of the first explosions at the Chernobyl-4 reactor occurred at 01:23:45-50 on April 26, 1986. The large amount of radioactivity release continued about 10 days due to the graphite fire at the reactor core. Figure 1 shows daily release of radioactivity based on the data given in the report the USSR government presented to IAEA in August 1966 (1986 USSR Report) [1] Depending on the fluctuation of wind direction, radioactive plumes flew to various directions from the destroyed reactor. Figure 2 indicates changes of wind directions and the contamination pattern during the period of large radioactivity release [2]. On April 26, the first strong radioactive plume moved to the west direction. Then, on April 27-28, radioactive plumes contaminated north-west and north areas. The basic pattern of the contamination near the Chernobyl power plant (ChNPP) was considered to be formed in the first three days. After that, the plumes direction moved to east and south directions.

On April 27, the next day the accident, the Pripyat city where workers of ChNPP were living was evacuated. Meanwhile, the people living in settlements other than Pripyat were left uninformed about the accident. It was on May 2 that the evacuation of all people within the 30-km zone was decided [3]. The evacuation finished around May 10. That is, these evacuees had been in the strong contamination for one week or more. Therefore, these evacuees were supposed to receive far more radiation than Pripyat citizens.

Table 1 shows estimates of average external dose for evacuees from the 30-km zone given in 1986 USSR Report. It is noted that the average dose of 26,200 evacuees from 19 settlements within 15 km from ChNPP was 450 mSv, which is 14 times larger than the value for Pripyat citizens of 33 mSv. Unfortunately, detailed information how to obtain these values was not given in the report.

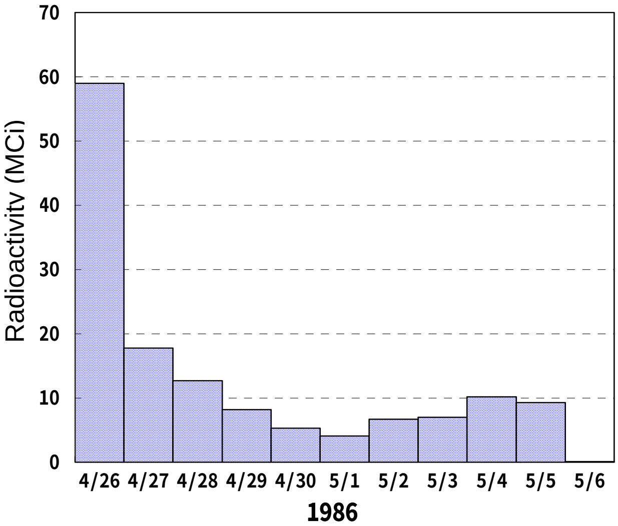

Fig.1. Daily radioactivity release, excluding noble gases.

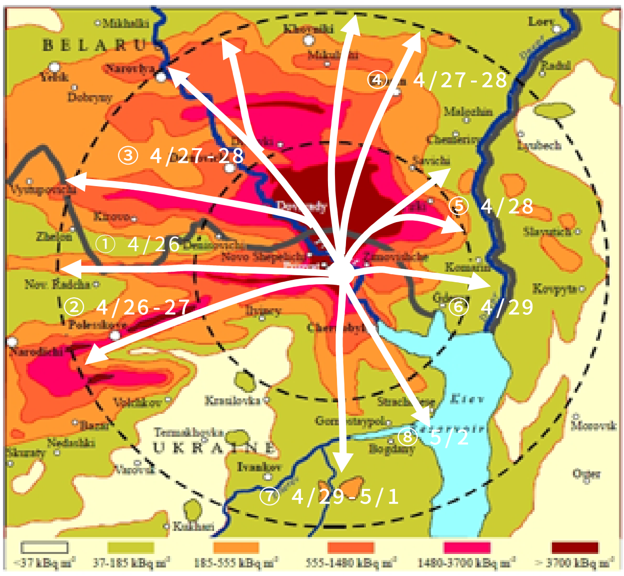

Fig.2. Daily direction of radioactive plumes on the back of ^{137}Cs contamination map. Made from Izrael's paper [2]

Table 1. Average external dose of evacuees reported in the 1986 USSR report

Distance from the Chernobyl site	Number of Settlement	Population (persons)	Average external dose(mSv)
3 - 6 km	(Pripayt)	45,000	33
3 - 7 km	5	7,000	540
7 - 10 km	4	9,000	460
10 15 km	10	8,200	350
15 - 20 km	16	11,600	52
20 - 25 km	20	14,900	60
25 - 30 km	16	39,200	46

On the other hand, Chernobyl Forum, which was organized by IAEA and other international institutions to summarize 20 years of investigation on the consequences of the Chernobyl accident, reported that the average dose of the evacuees from the 30-km zone was 20-30 mSv and the maximum was several hundred mSv [4]. The main source of the Chernobyl Forum report was considered to be the study by Likhtarev et.al for Ukrainian evacuees [5], in which the average external doses of 11.5 and 18.2 mSv were estimated for evacuees from Pripyat and other-than-Pripyat, respectively, by combining daily radiation survey data in settlements within the 30-km zone with individual questionnaires on the behavior after the accident. It is noteworthy that the dose ratio of Pripyat to other-than-Pripyat is obtained 1.6, while the corresponding ratio of the 1986 USSR report is 4.8. Although the detailed data about in the Pripyat city was shown in reference, the daily radiation survey data were not shown for other-than-Pripyat settlements in the 30-km zone [5].

Radiation survey data within the 30-km on May 1, 1986

In March, 1986, at an international conference for the 10th anniversary of the Chernobyl accident held in Minsk, an interesting map (Fig. 3) was presented about radiation exposure survey data on May 1, 1986, five days after the accident in settlements within the 30-km zone was released [6]. The maximum of 3,306 µGy/h

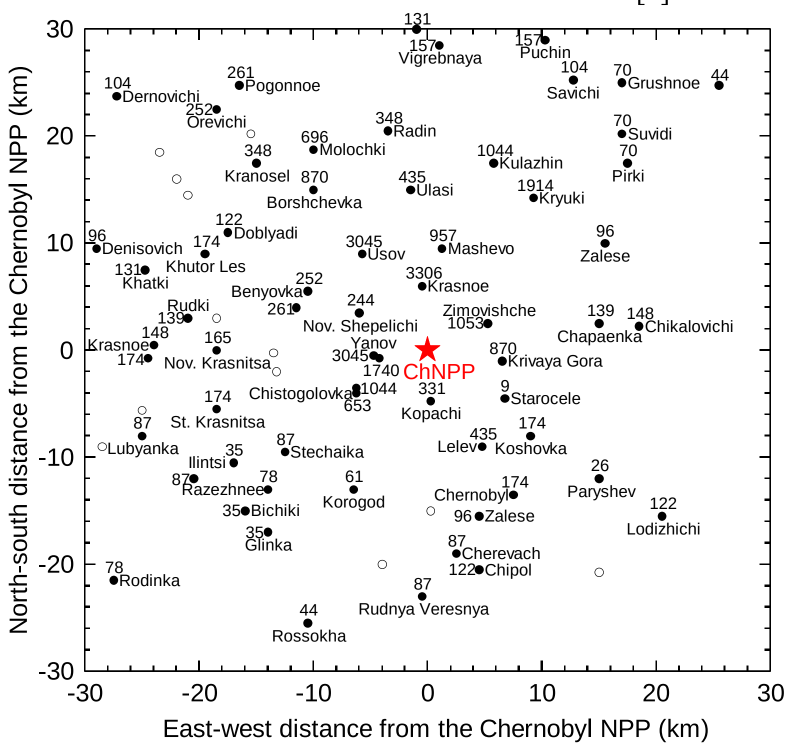

Fig.3. Dose rate in the 30-km zone on May 1, 1986,µGy/h.

(380 mR/h) was seen in Krasnoe village located 6 km north of ChNPP. This dose rate equals 80 mGy/day.

In the same report, the time trend of dose rate per unit ^{137}Cs deposition measured at Khoiniki located 50 km north from ChNPP was also presented, which was shown as diamonds in Fig. 4. The solid curve (Calculation 1) is calculation by Imanaka, assuming fallout composition given by Izrael et.al [7] as well as dose rate conversion factors (Table 2) [8]. The dotted curve is obtained by reducing the deposition ratio of Zr-Nb to half of Izrael's values. Calculation 2 could reconstruct the dose rate change well at the early stage of the contamination.

Assuming that all radioactive contamination in Krasnoe occurred at 12:00 on April 27 and all residents were evacuated at 12:00 May 3, Imanaka estimated the average dose in Karasnoe to be of 0.48 Sv, including internal exposure from inhalation. In the process to obtain this vale, the average body shielding coefficient of 0.8 (Sv/Gy) and the average occupation-shielding factor of 0.62 were used from the Likhtarev paper [5]. Taking into consideration the distribution of individual doses, it was concluded that 18 % of residents in Krasnoe could receive external dose more than 1 Sv, a criterion of acute radiation syndrome [8].

Our estimates of radiation dose for evacuees agreed with those given in 1986 USSR report, while about 3 times larger than those by Likhtarev et.al.

Table 2. Relative deposition composition (^{137}Cs=1) and dose conversion factor of nuclides deposited around the Chernobyl site.

Nuclide	Half life	Relative composition*	Dose factor (μR/h)/(Ci/km^2)
^{91}Sr	9.7 h	1.2	20
^{95}Zr	65.5 d	3.3	29
^{97}Zr	17 h	1.6	29
^{95}Nb	35 d	3.3	15
^{99}Mo	2.75 d	7.5	2.8
^{103}Ru	39 d	5.3	9.6
^{106}Ru	367 d	1.3	3.7
^{131}I	8.04 d	20	7.6
^{133}I	21 h	40	12
^{135}I	6.7 h	35	34
^{132}Te	3.25 d	33	46
^{134}Cs	2.05 y	0.5	29
^{136}Cs	13 d	0.3	39
^{137}Cs	30 y	1	11
^{140}Ba	12.8 d	3.6	43
^{140}La	1.67 d	3.6	39
^{141}Ce	32.3 d	3.5	1.8
^{143}Ce	1.38 d	3.1	4.9
^{144}Ce	284 d	2	0.55

*; Decay-adjusted at the time of the accident

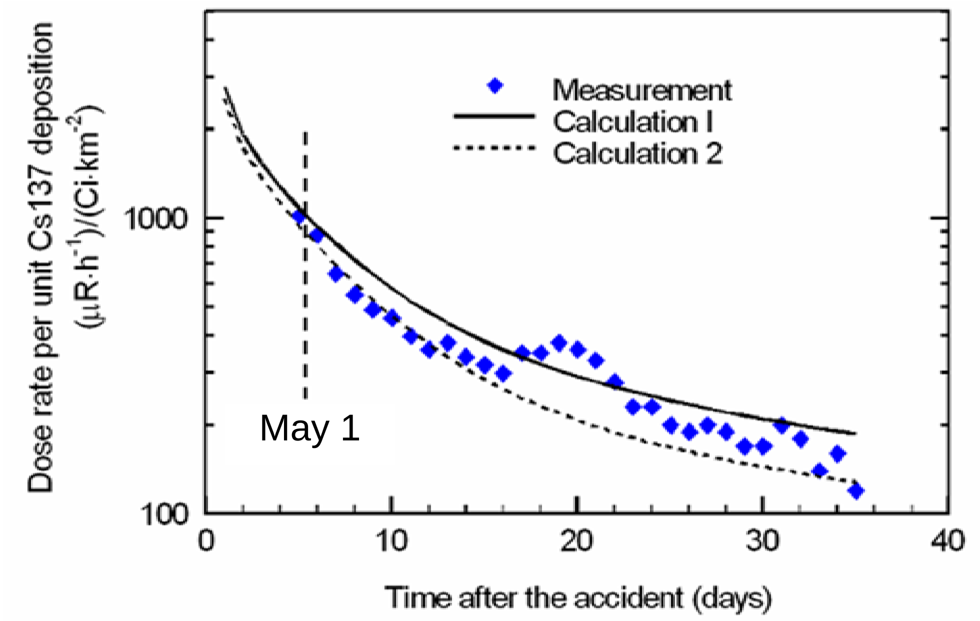

Fig. 4. Dose rate change in Khoiniki normalized per unit deposition of ^{137}Cs.

Radiation survey data within the 30-km zone on other days

In 2002, Muck et.al at GSF, Germany together with Ukrainian scientists published estimates of on inhalation dose for the evacuees from the 30-km zone [9], in which daily radiation survey data for the first two weeks in the 30-km zone were indicated. More details were found in GSF report [10]. Parts of daily radiation survey data are plotted in Fig. 5, divided directions around ChNPP into five sectors.

It is extremely surprising that maxima of exposure rate in Fig. 5 were not seen in April 26-28 when the strongest plumes were released, but in later days. For example, in two settlements of Chitogolovka and Tolsty Les in Sector-A (West) where the first radioactive plume passed over on April 26, the maximum of radiation exposure were recoded on May 3 and May 4, respectively, and no serious radiation increase was recorded in the firth three days. It is also noted that in Sector-C (North) the maximum value (3,300 μGy/h) in Krasnoe is seen on May 1, which corresponds to the maximum in Fig. 3 of 3,306 μGy/h.

Considering the plume directions and ^{137}Cs contamination pattern shown in Fig.2, it is difficult to accept the exposure rate trends of Fig. 5 as real ones, in spite of the description [6] that radiation survey was carried out every day in all settlements in the 30-km zone after the accident. Preferably we should consider that the

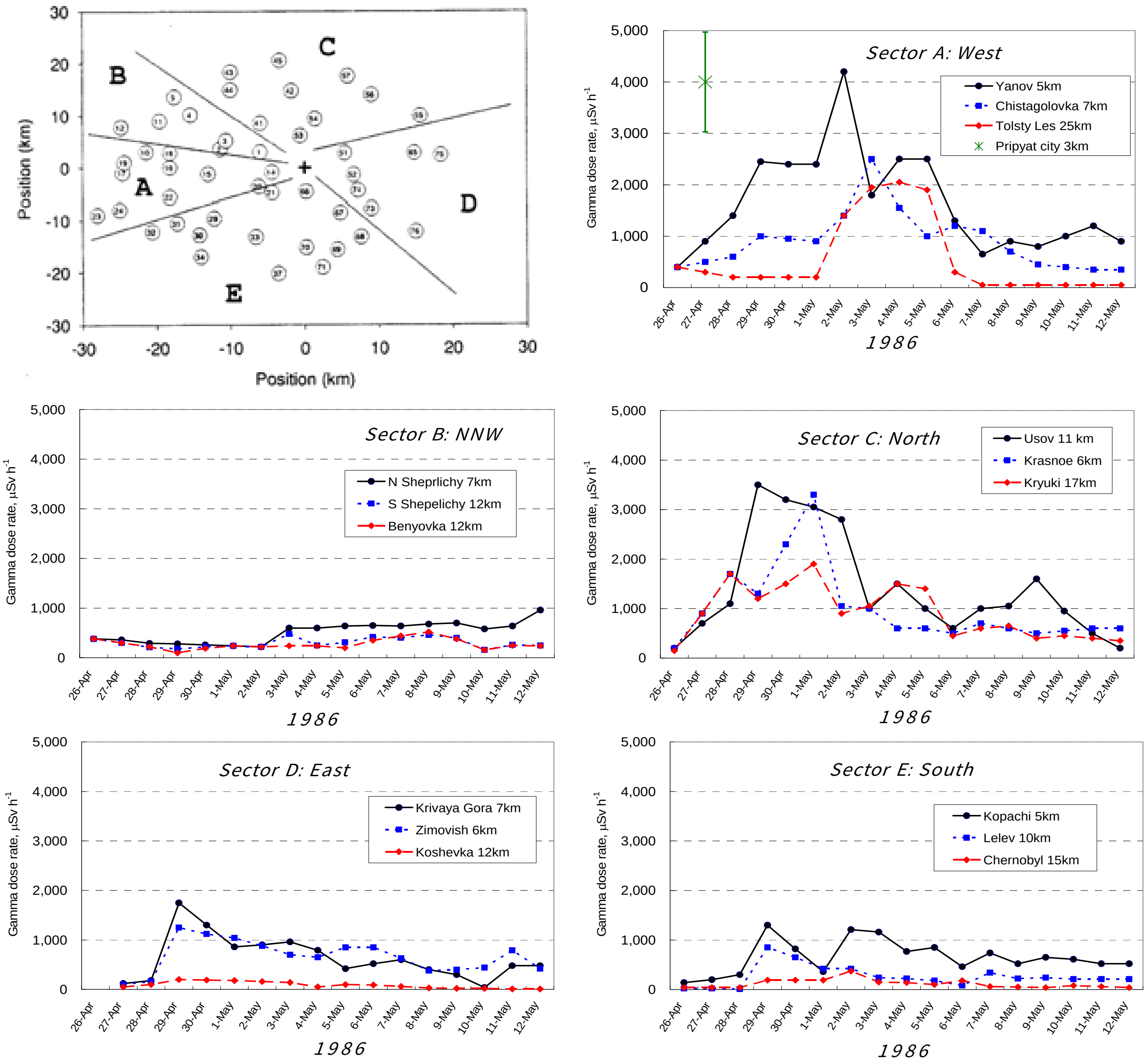

Fig. 5. Dose rate monitoring data supposed to be used in the previous study. A-E: direction sector.

monitoring activities in the first week for settlements within the 30-km zone were quite insufficient. Therefore, dose estimations that directly used the data of Fig. 5 could lead to underestimation of real values.

Our new estimation of external dose for evacuees

After detailed investigation of the radiation survey data shown in Fig. 5, we assumed that, although the plotted data in the first three days could not be accepted, the data of later period could be used to estimate external radiation of the evacuees, by extrapolating them to the earlier period. Examples of such extrapolation for Chistagolovka and Novaya Shepelichy villages are shown as dashed lines in Fig. 6. Then we assumed that the deposition occurred at a time at 12:00 April 26 and 00:00 April 27 in Chistagolovka and Novaya Shepelichy, respectively. The evacuation time at 12:00 May 3 was assumed for both villages. The results of external dose estimation based on the extrapolation method are shown in Table 3 (Model-1) together with estimates for several other settlements in different sectors.

We also applied another method to estimate external dose for evacuees (Method-2), in which external exposure was evaluated based on the amount of total ^{137}Cs deposition given in ref [10], relative deposition composition [11] and dose rate conversion factors (Table 2). The results by the Model-2 are also shown in Table 3. A reasonable agreement can be seen between the results by Method-1 and by Method-2.

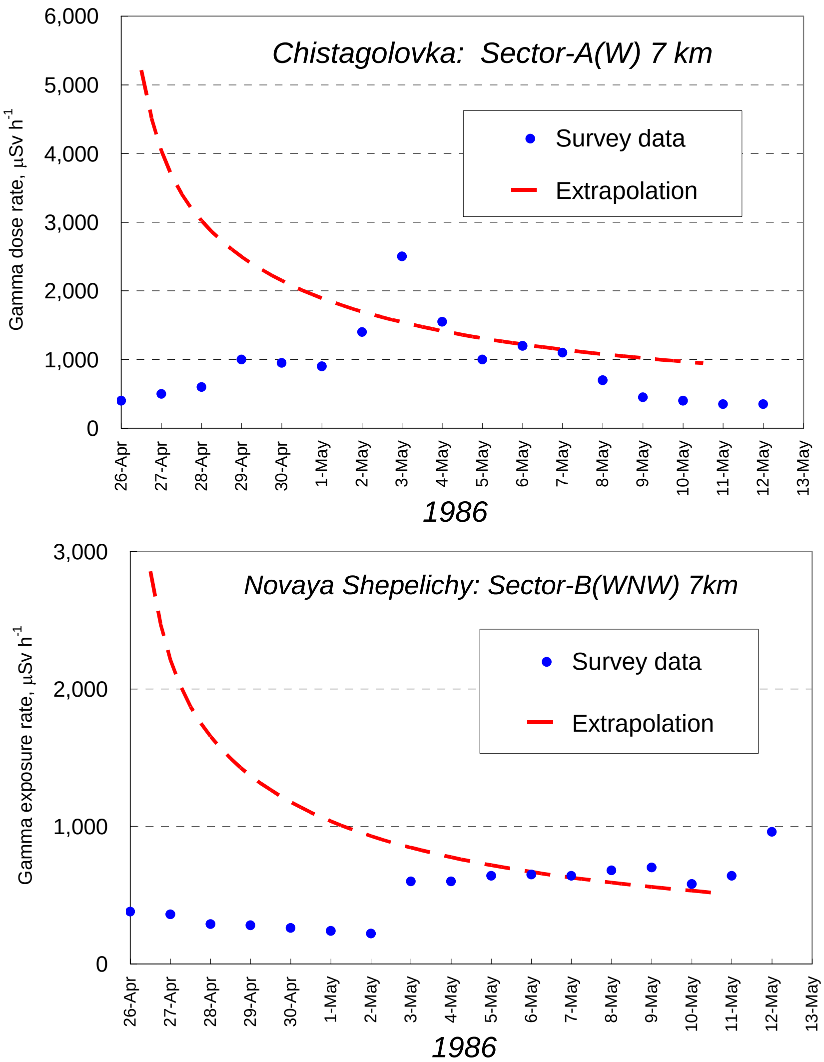

Fig. 6. Extrapolation of radiation survey data to the earlier period after the accident. Survey data between May 1 to May 7 were used for extrapolation of Chistagolovak. May 3 – May 9 was used for Novaya Shepelichy.

Table3 New external dose estimation based on two different methods as well as previous GSF/Ukraine values.

Sector	Village	Distance, km	Time of deposition	Date of evacuation	^{137}Cs density, kBq/m^2	Average external dose until evacuation, mSv		
						Present study		GSF/Ukraine (2000)
						Method-1	Method-2	
(A) West	Yanov	5	12:00April26	12:00April29	18,450	180	250	9.5
	Chistogolovka	7	12:00April26	12:00May 3	10,000	230	200	70
(B) WNW	N.Shepelichy	7	00:00April27	12:00May 3	3,530	96	72	13
	S.Shepelichy	12	00:00April27	12:00May 3	830	58	12	23
(C) North	Kryuki	17	00:00April28	12:00May 5	15,090	140	200	−
	Usov	11	00:00April28	12:00May 3	4,790	160	55	154
(D) East	Kryvaya Gora	7	00:00April29	12:00May 4	2,150	68	59	51
	Zimnovishe	6	00:00April29	12:00May 3	4,020	55	95	42
(E) South	Kopachi	5	00:00April29	12:00May 4	2,690	59	65	53
	Chernobyl	15	00:00April29	12:00May 5	1,780	14	14	6

Compared with the values given by GDF/Ukraine group, our new estimations indicate significantly larger values in Sector-A and Sector-Bt, while values in other sectors indicate agreement each other within an acceptable range. Considering that radioactive plumes began to contaminate Direction-D (East) and –E (South) after April 29, the agreement seen in Sector-D and –E might may reflect the situation that the systematic radiation survey in contaminate settlements other than Pripyat became effective at this period.

Conclusion

A clear discrepancy is seen between the contamination pattern around ChNPP and the daily radiation survey data used to evaluate external dose of evacuees. Reassessment is necessary especially west and north-west directions from ChNPP.

Refereces

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Early and Late Cytogenetic Effects Study in Groups Exposed Due to the Chernobyl Accident Using Conventional Chromosome Analysis and Fluorescence In-Situ Hybridisation (FISH) Technique

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Introduction

During last two decades a large body of scientific data have been accumulated by observations targeted to assessing and quantifying various biomedical effects in humans exposed to ionizing radiation due to the catastrophe at the Chernobyl nuclear power plant (Ukraine, former USSR) in 1986. It was commonly believed that Chernobyl-related radiation doses for the majority of affected individuals were clinically low, particularly not exceeding 1 Gy of equivalently acute low-LET rradiation, and that was confirmed by the absence of stable deterministic sindroms. But whatever low, those doses must be taken into account when late stochastic effect risk is calculated for the exposed populations, which are generally subdivided into three main categories: (i) the population evacuated from 30-km exclusive zone around the Chernobyl NPP and some nearby regions heavily contaminated with radionuclides, (ii) clean-up workers ("liquidators") who were irradiated during their duties in the Chernobyl zone and (iii) people who continue to live in areas with increased levels of radioactivity [1].

The cytogenetic analysis based on chromosomal aberration scoring in cultured human peripheral lymphocytes appeared to be one of the most demanded techniques for monitoring the Chernobyl critical groups. Firstly, post-Chernobyl cytogenetic research provided fundamental radiobiological data about spectrum and magnitude of genetic damage caused in human somatic cells by Chernobyl genotoxic factors, amongst which ionizing radiation dominated, but chemical agents also played quite a noticeable role [2-5]. But more importantly, the cytogenetic method was applied so intensively because of its ability to serve as the most powerful tool for biological dosimetry [6]. It should be fairly noted that initial steps of chromosomal dosimetry in the post-Chernobyl critical groups sometimes suffered from limitations due to specific irradiation scenarios (chronic or protracted exposure) and low number of cells scored per person when huge number of cases required rapid cytogenetic screening. With time pass after the accident a natural process of elimination of lymphocytes carrying unstable chromosomal aberrations comprised another big problem for conventional chromosomal biodosimetry, and stable chromosome aberration analysis using fluorescence *in situ* hybridization (FISH) technique also didn't provide an ideal alternative at the beginning of its application into real biodosimetry practice. It took about 20 years to develop proper methodological approaches which allow satisfactory overcoming the majority of listed problems [4, 7-10].

Regarding cytogenetics, evacuees from the 30-km Chernobyl exclusive zone have remained less investigated in compare with liquidators and inhabitants of radioactively contaminated areas. That could be a result of the lack of specialized cytogenetic laboratories in research institutes and hospitals, where initial examinations of those persons took place. Nevertheless cytogenetic data in evacuees were obtained by research groups from Minsk [11], St. Pitersburg [12], Moscow [2, 13] and Kharkiv (Ukraine) [3]. But only the Radiation Cytogenetics Laboratory of Kharkiv Institute for Medical Radiology started the cytogenetic survey in this group nearly immediately after the accident (since 28th April 1986). We carried out our study during long period of time, with several time-effect points gathered in randomly sampled cohort between the first few days and 14 years after evacuation. The summary results of these investigations performed by conventional cytogenetic analysis and additional data concerning the possibilities of retrospective biological dosimetry using FISH technique in Chernobyl evacuees and chronically exposed residents of radioactively contaminated areas are presented in this paper.

Materials and Methods

Study groups

In total 112 evacuees had been investigated by the conventional chromosome analysis. They were 50 adult males and 52 adult females, age ranged from 23 to 66 years, and also 10 children 4 to 17 years old. Blood samplings for cytogenetic assay were done in the time range from 2 days to 14.8 years after the departure from the Chernobyl exclusive zone. Amongst them there were 18 individuals (7 males and 11 females, age ranged from 16 to 55 years), for whom FISH analysis was also carried out in period 12.8-14.8 years after evacuation. The studied evacuees group did not contain cases of acute radiation syndrome, local skin and soft tissue injuries or cancer.

Another examined group consisted of 21 residents of radioactively contaminated regions of Belarus (6 males and 15 females). They were children at the time of the Chernobyl accident and continued to live in areas with increased levels of radionuclide deposition. Their age varied from 15 to 26 years at the time of blood sampling which was performed 12.8-14.8 years after the Chernobyl accident. This group was investigated by FISH technique only. Blood samples from the Belorussian residents group were collected at the Institute of Genetics and Cytology (Minsk, Belarus) and passed to the National Radiological Protection Board of the United Kingdom (NRPB, currently HPA-RPD) for cell culturing, and then coded metaphase preparations were transferred to the KhIMR for further FISH analysis.

Control group established for conventional chromosomal assay consisted of 50 healthy persons (19 males and 31 females), unexposed inhabitants of Kharkiv region aged from 19 to 58 years (mean 33 years). Amongst them a subgroup of controls for FISH study was formed, comprising 5 males and 7 females, aged from 19 to 58 years, randomly selected in trying to cover the age ranges in both exposed groups.

Cell culturing, conventional analysis, FISH painting and aberration scoring

The details of techniques and aberration scoring criteria used at KhIMR Radiation Cytogenetic Laboratory during investigations in post-Chernobyl human cohorts were published earlier [3-5, 8-10]. Briefly, throughout all the period of investigations the unified method of peripheral blood lymphocyte culturing was used with PHA-stimulated lymphocyte cultures set up for 48-50 h, metaphases harvesting after 4 h colchicin treatment and fixing in methanol/acetic acid mixture, that well corresponds to the standard technique described in IAEA manual [6]. From each sample replicated slides were prepared, coded and either stained by Giemsa for conventional analysis or processed by FISH technique according to the protocol [14].

For conventional assay all cytogenetic abnormalities recognised without special karyotyping were recorded, i.e. dicentrics and centric rings, both accompanied by acentric, excess acentric fragments, chromatid breaks and exchanges (combined below into total chromatid aberrations), hyper- and polyploids (combined below into total genomic abnormalities; all polyploids found didn't contain replicated aberrations; virtually all hyperploids represented threesomics, i.e. 47 chromosomes).

For FISH assay slides were FITC painted, highlighting chromosome combinations 1, 2 and 4 (Cambio), other chromosomes were counterstained with DAPI (diamidino-2-phenylindole), pancentromere probes (Oncor) that fluoresced red were also applied. Slides were examined under fluorescence microscopes (Nikon, Zeiss) equipped with filter sets for FITC, DAPI and all three fluorochromes vizualizing. Aberrations were counted in cells containing 46 centromeres and diploid amount of painted material from FITC-highlighted chromosomes. Translocations were recorded using the modified hybrid of conventional/PAINT descriptive nomenclature as complete t_{comp} or incomplete $t_{inc}Ab$ and $t_{inc}Ba$. The latter were subdivided into three subgroups: involving an unshortened painted chromosome – $t_{inc}Ba^*$, accompanied by a fragment from the painted chromosome – $t_{inc}Ba$+ac, involving a markedly shortened chromosome with no missing painted fragment present somewhere in the cell – $t_{inc}BaMP$ (“missing part”). Insertions of Aba and Bab-types were pooled into one category. Each exchange, either complete or incomplete, was accounted as an entity. Deleted painted chromosomes with a segment absent, dicentrics and centric rings accompanied by fragment and excess acentrics in painted chromosomes were also recorded for data completeness.

Statistical analysis

From 50 to 1200 metaphases were analyzed per person. Numbers of actual cells scored by FISH assay were converted into genome equivalents by monocolour version of Lucas’ formula for the sum of DNA content in highlighted chromosomes [15, 16].

When individual data were pooled, the randomness of the individual aberration yield distribution within the group was checked and weighted mean yields of cytogenetic damage were estimated. Standard errors for the mean were calculated from the observed dispersion of the cytogenetic damage yields amongst individuals that nearly always was close to Poisson statistics. For intergroup data comparison Student’s *t*-test was applied.

Results and discussion

The yield of aberrations measured by conventional analysis: general characteristics and time course

Kharkiv region remained non-polluted by the Chernobyl fallout and therefore comprised one of the main destinations for the routs of evacuation of citizens from town Pripiat’ and nearby villages located within 30-km exclusive zone around the Chernobyl NPP. Thus initial decontamination procedures and biomedical examinations of exposed persons were carried out by specialised departments and laboratories of the Kharkiv Institute for Medical Radiology (KhIMR). Chernobyl-related cytogenetic research started at KhIMR 28th April 1986, i.e. just 2 days after the catastrophe, and continued for the following 15 years.

Individual cytogenetic data in evacuees were combined depending on time gap between departure from the Chernobyl zone and investigation (Table 1). Within each group the individual aberration yields appeared at random. The individual values of total aberration frequency varied from 1.2 to 12.0 per 100 cells in groups studied up to 1 year after exposure; later that range narrowed to 0.0-5.0 per 100 cells. Dicentrics and centric rings accompanied by fragment represented a significant proportion amongst chromosome type aberrations: 30-40 % at the beginning of the observation, 18-29 % later, in compare with 13.4 % in the control group. Cells with more than 1 chromosome exchange were not found, thus aberration-per-cell distribution in that cohort was in a good agreement with Poisson statistics.

Table 1. Total cytogenetic damage yields in evacuees sampled at various times after their departure from the 30-km Chernobyl exclusive zone

Time after evacuation		Number of persons	Cells scored	Mean cytogenetic damage yield per 100 cells ±SE			
range	mean ± SE			Aberrant cells	Chromosome aberrations	Chromatid aberrations	Genomic abnormalities
1-9 days	4.25±0.65 d.	20	2316	4.66±0.54	2.94±0.36	1.77±0.34	0.48±0.15
0.2-1.0 y.	0.73±0.03 y.	40	4221	5.19±0.39	3.61±0.29	1.85±0.21	0.31±0.08
1.4-3.7 y.	2.13±0.11 y.	20	2065	4.65±0.60	2.52±0.40	2.61±0.51	0.34±0.13
4.6-10.7 y.	7.99±0.87 y.	14	3603	2.66±0.38	1.72±0.26	1.17±0.22	0.17±0.10
12.8-14.8 y.	14.32±0.15 y.	18	9314	1.48±0.21	0.64±0.14	0.91±0.12	0.14±0.04
Controls		50	19289	1.24±0.11	0.62±0.09	0.66±0.07	0.08±0.02

Here and in other tables: SE is a standard error for the mean; chromosome aberrations don’t include abnormal monocentrics resulted from translocations and insertions; genomic abnormalities comprise the sum of hyper- and polyploids.

Up to 2 years after exposure the mean frequency of aberrant cells remained on the plateau of the 4-fold excess above control, the mean yields of chromosome type aberrations and genomic abnormalities were 4-6 times higher and chromatid type aberrations – 3-4 times higher than the respective spontaneous values ($p<0.001$ for all end-points). Later an elimination of lymphocytes carrying chromosome aberrations took place, and the difference between evacuees and controls became statistically insignificant for genomic abnormalities approximately 8 years after exposure, for chromosomal rearrangements – 14 years after departure from the Chernobyl zone.

According to well known mechanisms of cytogenetic damage formation in mature human lymphocytes, the over-spontaneous excess of chromosome type aberrations, particularly dicentrics and centric rings in evacuees can be attributed to ionizing radiation exposure, but elevated yield of chromatid aberrations, polyploids and aneuploids should be considered as fingerprints of chemical genotoxic action or non-specific, stress-related endogenous mutagenesis (for details see [7]). In our opinion, the most possible source of chemical genotoxic action could be various compounds released from the reactor and also some reagents used during firefighting and decontamination procedures. The conclusion about appearance of those chemical factors in the environment due to the the Chernobyl accident is confirmed by the finding of the same spectrum and very similar quantitative outcome of cytogenetic damage inspecific to radiation in Chernobyl clean-up workers [17, 18].

The time course for dicentric and centric rings yield in evacuees is presented in Fig. 1. The general tendency for this end-point was gradual disappearence. However, the phenomenon of an initial rise of the dicentrics plus rings frequencies over one year was found, that can be explained by continuing exposures from short-lived radionuclides. After that aberration yield declined quite rapidly and in 14 years after irradiation it nearly reached the control level.

Dependence on age, gender and departure time

Regarding these results, the following analysis of cytogenetic data in relevance to age and gender was concentrated on 60 persons examined within 1 year after evacuation, when the dicentrics plus centric rings yield didn't start a decrease (Table 2). In control donors subdivided into appropriate subgroups no difference for cytogenetic parameters was found between males and females, and the same occurred for non-exposed individuals of different age, with the only exception of excess chromosome acentric

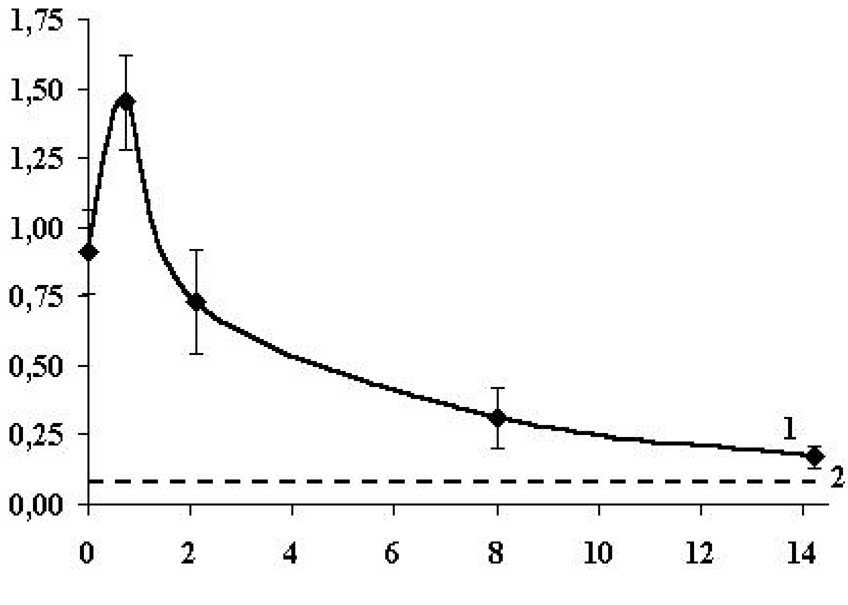

Fig. 1. Time effect relationship for the mean dicentrics plus centric rings yield in evacuees from the 30-km Chernobyl zone (1) in compare with controls (2). Y axis – aberration frequency per 100 cells; X axis – time after departure, years. Vertical bars represent standard errors of the mean.

Table 2. Early cytogenetic damage levels in evacuees depending on age and gender

Group formation parameter	Group	Number of persons	Mean cytogenetic damage yield per 100 cells ±SE			
			Dic+CR fr	Excess acentrics	Chromatid aberrations	Genomic abnormalities
Age	4-17 years	10	0.92±0.26	1.30±0.32[a]	1.53±0.28	0.31±0.19
	23-35 years	30	1.31±0.20	2.18±0.20[b]	1.96±0.30	0.50±0.11
	36-66 years	20	1.39±0.21	2.52±0.35[c]	1.78±0.29	0.20±0.11
Gender	Females	28	1.26±0.19	2.22±0.24	1.89±0.29	0.50±0.13
	Males	32	1.25±0.18	2.02±0.23	1.76±0.22	0.26±0.08

Dic+CR fr are dicentrics and centric rings accompanied by fragment; a, b & c – the spontaneous level of excess acentrics in the respective age subgroups in control, that were a = 0.09±0.09; b = 0.37±0.11; c = 0.91±0.22 per 100 cells.

fragments yield (for acentrics see footnote for Table 2; for other cytogenetic damage data not shown, as they didn't differ from the mean control values presented in Table 1 and Fig. 1). No changes in chromatid aberrations and genomic abnormalities levels were observed with evacuees' age. The difference for dicentrics plus centric rings yield between the youngest and the oldest age subgroups didn't reach the statistical significance ($p>0.05$), but the tendency for lower yield of radiation-specific chromosome exchanges in children may reflect some attempts to minimize the radiation load for youth, probably by limiting their outdoors activity between the accident and evacuation. The positive age dependence for excess acentric yield in evacuees was obviously related to the similar tendency for the spontaneous level in control donors. The statistical difference between respective evacuees and controls age subgroups for each cytogenetic end-point was equally highly significant ($p<0.001$).

No obvious influence of gender on cytogenetic parameters was initially found in evacuees, but when children were excluded from the data analysis a statistically higher yield of chromatid exchanges was observed in young adult males in compare with young adult females ($p<0.05$), and the latters also had an increased outcome of poliploids in compare with three other age/gender subgroups (Fig. 2). The possible reasons for those differencies, particularly active smoking status in young males and higher intensity of endogeneous mutagenesis resulted from more reactive neuro-humoral response to psichological stress in young females, were discussed earlier [5].

The initial phase of the time course for unstable aberrations yields was compared between

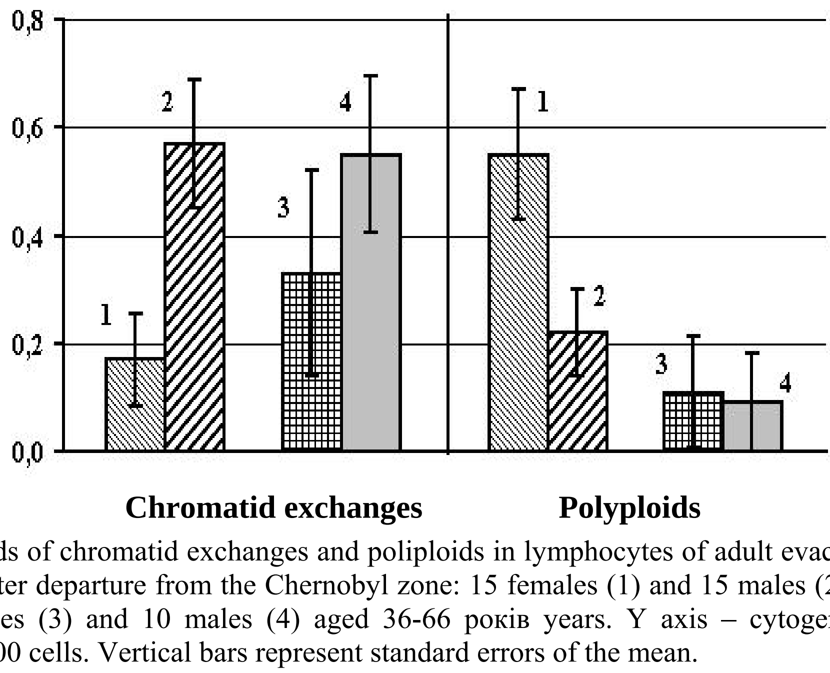

Fig. 2. The yields of chromatid exchanges and poliploids in lymphocytes of adult evacuees samples within 1 year after departure from the Chernobyl zone: 15 females (1) and 15 males (2) aged 23-35 years, 10 females (3) and 10 males (4) aged 36-66 років years. Y axis – cytogenetic damage frequency per 100 cells. Vertical bars represent standard errors of the mean.

Table 3. Chromosomal rearrangements in evacuees with different time of departure from the Chernobyl zone

Time between explosion and evacuation	Time between evacuation and blood sampling	Number of persons	Mean aberration yield per 100 cells ±SE		
			Dic+CR fr	Excess acentrics	Chromatid breaks
2 days	4.2±0.8 d	13	0.87±0.16	2.60±0.36	1.60±0.42
	0.79±0.03 y	22	1.30±0.24	1.95±0.22	1.18±0.19
	2.20±0.14 y	10	0.58±0.24	1.75±0.61	1.36±0.62
3-11 days	5.7±1.2 d	7	0.98±0.35	0.98±0.29 [a]	1.48±0.41
	0.66±0.05 y	18	1.65±0.33	2.45±0.36 [b]	1.82±0.31
	2.07±0.17 y	13	0.87±0.29	1.83±0.40	3.47±0.57 [a,b]

The difference is statistically significant ($p<0.05$): a – between subgroups "2 days" and "3-11 days" at similar time after exposure; b – in compare with the first time point inside the subgroup "3-11 days".

evacuees with different time of departure from the Chernobyl zone (Table 3). During the first two years after exposure chromatid break yield slightly declined in persons evacuated in 2 days after the accident but increased in those who left the Chernobyl zone later. These changes appeared to be associated with chromosome acentrics behaviour that was expessed as elimination in the former evacuees' subgroup and stability in the latter. The initial increase of dicentrics plus centric rings yields during 1 year after irradiation appeared to be a common feature for all evacuees but was more pronounced in persons who were evacuated from 3 to 11 days after the accident compared with those who left sooner; just 2 days after the explosion, and this tendency could be traced during 2 years after exposure. As the duration of exposure in evacuees had such a remarkable influence on the aberration outcome, it was judged as a main factor to be considered during biological dose estimating, in addition to the known role of exposure protraction in deriving an appropriate dose-response equation from a standard acute calibration curve for chromosomal dosimetry [6].

The observation of significantly increased level of chromatid aberrations in evacuees, apart from detection of chemical impact, provided a serious implication for biodosimetry: the list of end-points suitable for dose reconstruction must be restricted to dicentrics and rings only, with all excess acentrics excluded, because the latter could be caused with quite high probability by chemical mutagens either directly or as derived from chromatid breaks in lymphocyte precursors.

Biological dose estimations based on conventinal analysis data

To carry out the radiation dose estimation the individual dicentrics plus centric rings yields from evacuees investigated during non-elimination phase of those aberrations dynamics (i.e. within 1 year post-exposure) were pooled in two subgroups depending on when they left the exclusion zone – 2 days or 3-11 days (Table 4). In both groups, chromosome aberrations appeared at random amongst individuals, and the parameters of distribution were close to Poisson statistics that indicated an absence of persons significantly overexposed in compare with others inside the groups. Thus, carrying out group biodosimetry was methodologically correct.

According to the IAEA Chromosomal Biodosimetry Manual [6], mean doses for the evacuees groups were calculated by referring their mean dicentrics plus centric rings yields to intralaboratory *in vitro* dose response curve constructed for acute γ-exposure within low dose range [7], with quadratic coefficient reduced by the Lea & Catchiside G-function, which takes into account the exposure duration. Thus the dose response equation $Y = c + \alpha \bullet D + \beta \bullet G \bullet D^2$ was solved using the following parameters: the spontaneous level of aberrations c=0.08 per 100 cells and linear term α = 2.98 per 100 cells per Gy for both groups; initial acute quadratic term β = 8.05 per 100 cells per Gy^2 was reduced to 1.5 per 100 cells per Gy^2 for persons evacuated in 2 days after the accident and to 0.52 per 100 cells per Gy^2 for those who left later (average departure time was 7 days after the explosion).

Table 4. Individual dicentrics plus centric rings yields distributions and mean biological dose estimations in former citizens of t. Pripiat' and 30-km Chernobyl exclusive zone depending on time of their evacuation

Departure after the accident (number of persons)	Individual Dic+CR yield per 100 cells					Mean Dic+CR yield per 100 cells	Biological dose estimation, mGy
	0	1	2	3	4-5		
	Number of individuals						
2 days (35)	9	15	9	2	0	1.13±0.17	300±29
3-11 days (25)	5	10	7	2	1	1.44±0.20	420±39
Total (60)	14	25	16	4	1	1.25±0.13	360±16

Table 5. Aberration levels measured by FISH technique in Chernobyl groups in compare with controls

Group (number of persons)	Genome equivalents scored	Aberration frequencies ±SE per 100 genome equivalents (actual numbers are given in parenthesis)							
		Dicentrics +Rings	Acentric fragments	t_{comp} (Ab+Ba)	t_{inc} (Ab)	t_{inc} (Ba*), (Ba+ac)[a]	t_{inc} (BaMP)	Insertions	Deleted chromosomes
Controls (12)	4088	0.10±0.04 (4)	0.66±0.11 (27)	0.37±0.05 (15)	0.42±0.06 (17)	0.07±0.03 (3)	0.29±0.06 (12)	0.07±0.04 (3)	1.44±0.12 (59)
Evacuees (18)	5282	0.17±0.05 (9)	0.98±0.13 (52)	0.57±0.07 (30)	0.63±0.10 (33)	0.15±0.07 (8)	0.44±0.10 (23)	0.13±0.06 (7)	2.08±0.27 (110)
Residents of RCA (21)	7916	0.10±0.03 (8)	0.71±0.12 (56)	0.29±0.05 (23)	0.44±0.07 (35)	0.10±0.03 (8)	0.21±0.05 (17)	0.09±0.03 (7)	1.20±0.14 (95)
Spontaneous levels for inhabitants (mean age 21 yrs)[b]		0.10±0.04	0.54±0.16	0.22±0.02	0.27±0.02	0.00	0.18±0.02	0.02±0.01	1.17±0.04

RCA – radioactively conraminated territories. [a] – one t_{inc} (Ba+ac) was detected in the control group, one in evacuees group and six in residents group. [b] – applying age-effect regressions for complete translocations, insertions and deleted chromosomes and real yields of acentrics and incomplete translocations observed in a subgroup of young control donors [6].

The resulted dose estimate of protracted irradiation appeared to be 1.4 times higher in those persons who were evacuated during the period 3-11 days after the accident that was well in line with irradiation scenario. To the best of our knowledge, these are the only results of direct (i.e. early dicentric) biodosimetry obtained for the Ukrainian Chernobyl evacuees in accordance with methodological requirements of IAEA Manual [6]. A group of Belorussian children evacuated from contaminated areas soon after the reactor explosion and examined cytogenetically in short time after exposure by authors [11] showed quite similar dicentric yields and similar resultant dose estimates to that of in our study.

However, any biodosimetry data limited to group mean dose only, whatever useful, seems to be not informative enough for epidemiologists, who also need a picture of individual dose distribution within exposed cohort. It turned to be a real challenge due to very large statistical uncertainty of individual dose assessments occurred with low number of aberrations (up to 5) found in limited number of cells (typically, 100) scored per person in early post-accident period. Moreover, the significant proportion of all cases were those with zero dicentrics observed, so according to classic biodosimetry the zero should be set as mean radiation dose for such individuals, but statistics showed that with zero dicentrics in 100 cells we can not exclude doses up to 0.5 Gy.

To solve this problem we applied a probabilistic approach, namely Bayesian analysis, that allows looking at aberrations as stochastic events, which occur with some probability and moreover can be detected (observed) also with some probability. The Poisson distribution of aberrations amongst cells seen in all exposed individuals in our study provided an opportunity to apply this function as a main part of *a priori – a posteriori* equation, which links the probability of existence of "true" number of aberrations in the sample in case when any particular number of aberrations is observed. The "true" number of aberrations divided by number of cells scored results into the "true" yield of aberrations, and that can be converted into absorbed radiation dose using an appropriate dose response curve. Initially we applied this approach and accordant mathematical algorithm to the group of Chernobyl clean-up workers that showed very satisfactory results [4, 10].

The probability distributions of absorbed dose were constructed for every evacuee in our study. It was done in two variants: using dose response relationship for protracted exposure but also for acute exposure. The later provided dose values which can be used in risk assessment without necessity of correcting data for relative biological effectiveness of protracted irradiation. All individual distributions were pooled together by combining the probability density in short dose intervals – 50 mGy, and in this

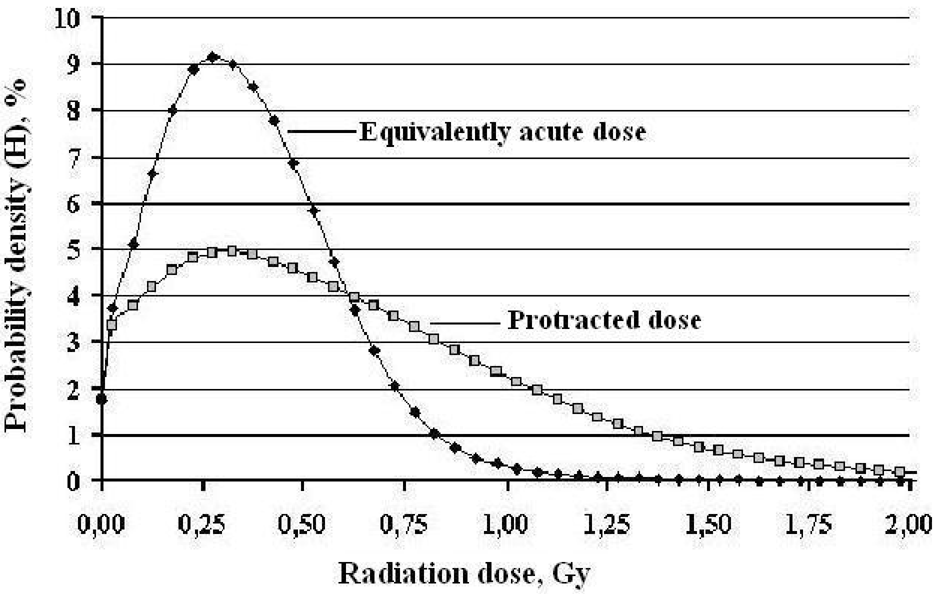

Fig. 3. Probability density distributions of protracted and equivalently acute doses of γ-irradiation estimated using Bayesian analysis applied to cytogenetic data in evacuees from t. Pripiat' and 30-km Chernobyl exclusive zone.

manner the total probabilistic distribution of protracted and equivalently acute radiation doses were finally obtained (Fig.3).

Mean dose of protracted γ-irradiation estimated from the total probability density distribution appered to be equal to that of obtained by classic biodosimetry data treatment. Modal protracted doses in evacuees fall within 200-400 mGy. Probability density up to 1 Gy of protracted exposure was the main part of total dose range, but about 20 % of protracted doses in evacuees exceeded this 1 Gy limit. The distribution of probability density for equivalently acute radiation doses within the interval from zero to 750 mGy appeared to be nearly symmetrical around modal values (tha same 200-400 mGy, as for protracted doses), and 99.8 % of all probability density of acute doses was contained by the dose range up to 1 Gy. Such data were in total agreement with clinical observations in those persons, particularly with absence of acute radiation syndromes.

It should be noted, that physical dose calculations for citizens of t. Pripiat', which represented the basis for "official" opinion about radiation doses to that population, resulted into estimations of average effective dose about 11.5 mSv, the maximum of individual dose about 114 mSv and 0.75 % of Pripiat' population exceeded the accidental permissible limit 50 mSv for public [19]. Obviously, these results were obtained by modeling involved many assumptions concerning irradiation conditions, and some factors seem to be not taken into account (e.g. remarkable external radioactive contamination of those evacuees), therefore the mentioned dose values were in controversy to our results of cytogenetic dosimetry carried out in the group of evacuees from t. Pripiat'. However, there is another set of physical dose calculations for this category of persons affected by the Chernobyl [20], where the estimations of accumulated doses appeared to be up to 1 Gy for inhabitants of certain villages around the reactor, and that was well in excess of estimates in publication [19], but in a good agreement with our data presented here.

Cytogenetic data and biodosimetry estimations resulted from the FISH assay

Regarding the debates around true radiation doses to evacuees from Chernobyl, who (in contrast to clean-up workers) were non-monitored by physical dosimetry, and for whom modeling dosimetry data appeared to be unsure, the necessity occurred for additional verification of chromosomal biodosimetry results. From the studies of time course of conventionally scored aberrations (see Fig. 1) it became obvious, that any attempts of applying the conventional cytogenetics based on unstable aberrations analysis several years after the accident wouldn't give sufficient results for biological dosimetry due to elimination of cells carrying dicentrics from the circulating lymphocyte pool [3, 6, 8]. Therefore the alternative approach based on stable chromosome rearrangements quantification should be used for estimating the yield of cytogenetic damage in lymphocytes of exposed persons. To solve this task, the last group of evacuees amongst five mentioned in Table 1 (12.8-14.8 years after exposure) was examined by both conventional cytogenetic analysis and FISH technique, specifically applied for stable aberrations visualizing. Simultaneously, a group of young residents of radioactively contaminated areas of Belarus' was also surveyed by FISH to check whether this method can serve as biodosimetry tool for quantifying low doses of not past, but long lasted chronic exposure.

Actual numbers of unstable and stable chromosome aberrations and their yields per 100 genome equivalents in studied groups are shown in Table 5. Cytogenetic parameters in evacuees were compared directly to those of in total control group due to similarity of mean age values. The spontaneous levels of translocations, insertions, acentrics and deleted chromosomes for inhabitants were calculated using age-effect regressions generated for our control group earlier [21]. Metaphases with complex rearrangements were rare and all aberrations from the complexes (apart from insertions) were included into appropriate columns of Table 5. Individual aberration yields were randomly distributed in consistence with Poisson statistics within both groups.

The average levels of dicentrics plus centric rings and acentric fragments in evacuees were slightly increased above control, but no statistical difference was observed ($p>0.05$). That was in a very good agreement with cytogenetic effects outcome measured by conventional method, confirming again the fact of elimination of lymphocytes with unstable aberrations from the circulating pool during years post-irradiation. The level of unstable aberrations in residents was even more close to spontaneous values than that of in evacuees that probably reflected very low dose rates during their living in contaminated areas.

In contrast to unstable aberrations, the average yields of stable rearrangements were markedly increased in exposed groups above control. However that was related mainly to exchanges, but not to deleted chromosomes. This type of chromosomal abnormalities was rarely reported to be measured in exposed persons, because they obviously resulted from the lost of chromosome acentrics or chromatid breaks during mitosis of the lymphocyte precursors, where fragments were initially induced. Both types of unstable aberrations have no exclusivity to radiation, so a low sensitivity of deleted chromosomes as an exposure marker after protracted or chronic irradiation to low doses could be concluded. Unlike deleted chromosomes, the stable chromosome exchange yields were increased above control, and the meaningful difference with spontaneous level occurred for t_{comp} in evacuees ($p<0.05$), t_{inc}Ab, t_{inc}Ba* plus t_{inc}Ba+ac and insertions in inhabitants ($p<0.05$-0.01). The total level of incomplete translocations was statistically elevated in both exposed groups ($p<0.01$-0.001). Noteworthy, the sum of incomplete translocations was 1.9-2.6 times higher than the level of complete ones. The ratio of t_{inc}Ab to total t_{inc}Ba translocations had similar values in evacuees (1 : 0.9) and residents (1 : 0.7).

The cytogenetic parameter applied for biological dosimetry was the yield of stable exchanges with actual or assumed full presence of chromosomal material in “stable” cells. That represented a combination of complete translocations, insertions, incomplete translocations t_{inc}Ba* and virtual proportion of t_{inc}Ab involving unshortrened chromosome – t_{inc}Ab*. The reasons of choosing this particular combination of parameters instead of total translocation level for practical purposes of retrospective biodosimetry were fully explained earlier [7].

Particularly, it was suggested that incomplete translocations with “missing part” had no exclusivity to ionising radiation and may occur as a result of segregations of chemically-induced balanced chromatid exchanges in dividing lymphocyte precursors [22]. The presence of increased level of chromatid exchanges in post-Chernobyl critical groups (including residents of contaminated areas) was reported in several independent studies [17, 18], and particularly for evacuees it can be seen in early conventional analysis results presented here. Thus for preciseness of radiation exposure detection the data analysis in Chernobyl groups has to be restricted to chromosome exchanges in cells with full presence of chromosomal material. Additionally, incomplete translocations accompanied by acentric fragments were also withdrawn due to instability of their wholeness during mitotic divisions of lymphocyte precursors. Elimination of acentrics would result in a lack of genetic material following by cell death or arising of incomplete translocations with “missing part” in daughter lymphocytes. It should be noted, that amongst three exposed groups a significant number of t_{inc}Ba+ac was detected only in inhabitants of radioactively contaminated areas that obviously reflected the radiation induction of this type exchanges directly in mature cells during lymphocyte lifetime. Therefore, the cytogenetic assessment of radiation doses accumulated years ago or during long term chronic exposure has to be based on the yield of chromosome exchanges formed without accompanying acentrics. Amongst incomplete translocations these were unshortened chromosomes with joined counterstained material that probably represented reciprocal exchanges involving a small telomeric region beyond the limits of visual resolution by FISH. Aassuming the identity of the mechanisms of tAb and tBa exchanges formation, the yield of t_{inc}Ab* was calculated by multiplying the number of total t_{inc}Ab by the respective fraction of t_{inc}Ba* within total t_{inc}Ba in studied groups. The obtained values were rounded off to the integer numbers and applied for deriving the full-genome yields of t_{inc}Ab*, which was used for calculating the total yield of stable chromosome exchanges as described above (the most full version of this approach was patented [23]).

The calibration dose-response curve for the mentioned end-point was constructed *in vitro* within a low dose range (up to 1 Gy) and fitted to a linear-quadratic model [7]. Taking into account the protracted exposure conditions in both Chernobyl groups the biological dose assessment was performed using only the initial linear slope of the curve, that was expressed by equation $Y = c + \alpha \cdot D$, where α=1.401 per 100 genome equivalents per Gy, and the background incidence of aberrations for evacuees was established in the total control group (c=0.55±0.09 per 100 genome equivalents), and that for young residents was calculated from the empirically generated regression $Y_{Sp}=0.11+2.68 \cdot 10^{-4} \cdot A^2$, where A is age in years (for A=21 years c=0.23±0.11 per 100 genome equivalents) [7, 21].

The mean yields of stable exchanges of 0.97±0.14 per 100 genome equivalents in evacuees and 0.44±0.06 per 100 genome equivalents in residents corresponded to protracted dose estimations about 300±130 mGy and 150±90 mGy, respectively (errors for mean doses were calculated applying Poisson standard errors for the excess of aberration level above control).

The results of retrospective FISH biodosimetry in evacuees were in a good agreement with early dose estimates based on conventional aberration scoring (see Table 4). In residents of contaminated areas the yield of dicentrics measured by FISH technique appeared to be unsuitable even for distinguishing exposed group from the control. It is well known that chromosomal biodosimetry utilizing unstable aberrations in chronically irradiated persons is a highly challenging task, which particularly can be solved using an elegant approach suggested by M. Sasaki [24]. We were happy to succeed with FISH-detected stable chromosome exchange yield, which provided another tool for identification of the exposed population and quantitative measurement of the low radiation dose.

From data present in literature concerning dose estimations by FISH analysis in Chernobyl cohorts one can see that biodosimetry performed by other authors were based on measuring the yield of either complete translocations alone or total translocations (including those with missing part of chromosomal material) [25-33]. Our approach with splitting translocations into “full presense of chromosomal material” and “missing part” categories seems to be unique in application to biodosimetry *in vivo*. Therefore our data have to be better compared with other authors’ results regarding total translocation levels or, even better, overspontaneous excess for this end-point in Chernobyl groups, rather than for dose estimations made by other laboratories. The literature analysis showed that in general our results of measuring the translocation yields were in a good agreement with other data presented for similar categories of persons exposed to ionizing radiation due to the Chernobyl accident [25, 28, 32, 33]. Thus, in total, retrospective FISH biodosimetry confirmed our early assessments of radiation doses accumulated by common population due to the Chernobyl NPP accident.

Conclusions

The cytogenetic survey carried out in population exposed to ionising radiation due to the catastrophe at the Chernobyl NPP showed the significantly increased level of unstable chromosomal aberrations in blood lymphocytes of individuals sampled early after the accident, and also the presence of markedly increased yield of stable chromosomal rearrangements was detected by FISH technique late time after irradiation. The time-course changes of chromatid type aberrations, chromosome type fragments, hyperploidy and polyploidy levels in evacuees were displayed as a gradual decline of chromosomal rearrangements and genome abnormality frequencies from the statistically elevated level in the first 1-2 years after the accident to the subcontrol meanings at the end of the 14-years period. The increased level of these cytogenetic damages indicated the role of the combination of mutagenic factors acted in the accidental situation at Chernobyl zone.

In Ukrainian evacuees from the Chernobyl zone both early dicentric assay and late FISH translocation measurement resulted in very similar mean dose estimates in range 300-400 mGy of protracted γ-irradiation. The yield of stable chromosome exchanges in Belorussian inhabitants of radioactively contaminated areas corresponded to doses of chronic exposure about 150 mGy.

According to our data, both evacuees from the 30-km Chernobyl exclusive zone and residents of radioactively contaminated areas should be considered as a category of exposed persons, who's radiation doses (especially if expressed in acute exposure equivalents) were below the threshold of induction of deterministic radiation syndromes, but high enough for expecting an increased risk for late effects occurrence on population level. Thus, development of advanced technologies in chromosomal analysis and, more importantly, gradual improvement of methodology of cytogenetic data interpretation allows obtaining meaningful practical results for biological dosimetry of past and chronic radiation exposure to low doses. Therefore medico-biological observations in Chernobyl groups have to be continued and early data can also be retreated and discussed using knowledge and experience obtained during post accident period by various scientific groups throughout the world.

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Some Issues of Long-Term Investigations on Genetic Consequences by the Chernobyl Accident

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1. SUMMARY

Results of almost 20-year investigations of possible consequences of the Chernobyl accident for Belarussian population, obtained by the National Research Institute for Hereditary and Inborn Diseases, provide grounds for the conclusion that at least four facts, related to genetic consequences, had connected to the Chernobyl accident: three could be defined as proven and one – as probable. The first three are:

- Significantly increased level of chromosome aberration in pregnant women and their newborn babies, who resided in 1986-1988 in zones with ^{137}Cs contamination of 555 kBq/m^2 and higher;
- Significant three-year increase of prevalence of embrional development defects in the same abovementioned zones and in the same years, which lead to the increase of prevalence of congenital anomalies in social abortuses, fetuses and newborns;
- January peak of babies with Down syndrome, born by women who were in the zones of maximum irradiation in the period 26-30 April 1986;

Of possible but not yet proven consequences we shall mention investigation in contaminated and control zones before and after the Chernobyl accident of the ratio of *de novo* structural chromosomal aberrations (SCA) to inherited SCA, which induce chromosomal diseases. This investigation revealed an increase of the share of *de novo* SCA in after-Chernobyl period. Etiology of observed changes is not uniform. While an increased level of chromosome mutations, including trisomies, is essentially induced by additional ionizing radiation, many congenital anomalies which determined increased frequencies of defects in 1987-1989, belong to the group of multifactoral defects, i.e. for their etiology important are radiation as well as nutritional problems, hormonal and immunological upheavals.

2. RESULTS OF INVESTIGATION OF CYTOGENETIC EFFECTS

Cytogenetic effects in pregnant women and their newborn babies who have lived in the regions with most severe contamination by Chernobyl fallouts (Gomel and Mogilev oblasts of Belarus) were investigated. Standard practices were used for cultivation of peripheral blood lymphocytes and registration of chromosome aberrations (G. Lazjuk et al., 1999). As could be seen from Table 1, all pregnant women and their fetuses received biologically effective doses of ionizing radiation, which resulted in increased numbers of dicentrics and ring chromosomes.

It appeared that mutagenic effect in evacuated pregnant women (group 1) was higher than in women who became pregnant 0.5-1 year after the disaster (group two) and women, who have lived more than 2 years on the territories with the soil contamination of 555 kBq/m^2 and higher. The level of dicentrics and ring chromosomes in newborns was also higher than in their mothers (0.38% and 0.32% in Gomel oblast, 0.21% and 0.19% in Mogilev oblast, respectively).

Table 1. Frequency of dicentrics and ring chromosomes in pregnant women and newborn babies in contaminated and non-contaminated regions of Belarus.

Regions	Investigated groups	Number of investigated metaphases	Frequency of rings and dicentrics
Gomel oblast	1st group*	14645	0.32
	Newborn babies of 1st group	9167	0.38
	2nd group**	7753	0.14
Mogilev oblast	3rd group***	7715	0.19
	Newborn babies of 3rd group	7486	0.21
CONTROL			
Novopolotsk	4th group****	4965	0.04
Minsk	Newborn babies	9670	0.04

- * - 1st group – pregnant women evacuated during May-June 1986 from districts of Gomel oblast with maximum contamination;
- ** - 2nd group - pregnant women who have lived more than a year in zones with ^{137}Cs contamination of 555 kBq/m^2 and higher;
- *** - 3rd group - pregnant women, who have lived more than two years in zones with ^{137}Cs contamination of 555 kBq/m^2 and higher;
- **** - 4th group – pregnant women of control group from the city of Novopolotsk

3. RESULTS OF INVESTIGATION OF THE PREVALENCE OF EMBRYONIC DEVELOPMENT DISRUPTIONS

Embryonic development disruptions were investigated by registration of congenital anomalies in social abortuses, infants and foetuses.

3.1. Results of investigation of social abortuses

By social abortion we understand the product of conception (embryo or fetus) was obtained after the termination of pregnancy on woman's request. Since the material was collected without sampling, it means that in fact this is a population investigation. Pregnancy terminations were carried out in specialized medical facilities by gynecologists, by curettage of uterine cavity when gestational age was 5 to 12 weeks. This material was investigated by embryologists of the National Research Institute for Hereditary and Inborn Diseases on non-formaline-fixed material with stereomicroscope and on histological sections. When necessary, cytogenetic investigations in cultivated tissues of embryos were carried out. The prevalence of embryonic development disruption was calculated for the number of investigated organs. The total number of investigated abortuses exceeded 31,000, of which 2,701 were received from the Chernobyl zone and the remaining were from Minsk, they were used as control. The frequency of embryonic development disruption in social abortuses from the contaminated areas was significantly higher than in Minsk during the same period (7.2% and 4.9%, respectively). Increase in malformations was observed in all systems of organs, while more significant prevalence was observed for cleft of lip and/or palate, dubling of kidneys and ureters, polydactyly and neural tube defects. The overwhelming majority of malformations in social abortuses are etiologically heterogenic and due to this reason an accurate estimate of the potential share of ionizing radiation in increased prevalences is impossible. Moreover, in our investigations we have not observed neither higher number of aneuploids, nor cluster death of cells during organogenesis, which are indicative for radiation effects.

3.2. Results of investigation of congenital anomalies prevalences

Prevalence of congenital anomalies was investigated in medical abortuses, obtained after termination of pregnancy due to genetic indications, in stillborns and newborns. Data of the national registry of congenital anomalies (collected since 1979 at the National Research Institute for Hereditary and Inborn Diseases) were used to this end. The details on the Belarus registry could be found in: G. Lazjuk et al., 2003 (7). In this paper we describe only the results of investigation of prevalence of strict registration congenital anomalies (SR CA). To this group belong anomalies which could be unambiguosly diagnosed in prenatal and neonatal periods. So, to SR CA group belong: anecephaly (Q00), spina bifida (Q05), cleft of lip and/or palate (Q35, Q37), polydactyly (Q69), limb reduction defects (Q71, Q73), digestive system atresia (Q39, Q39,2), anal atresia (Q42, Q42,3), Down syndrome (Q90), multiple congenital anomalies (Q86, Q87, Q89,7, Q91-93, Q96-99). Analysis of SR CA prevalence was carried out in 4 groups. The first group was represented by the material from 17 districts of Gomel and Mogilev oblasts, where there are territories with the surface density of soil contamination by ^{137}Cs from 555 kBq/m^2 and more, the 2nd group – control for the 1st group – 30 districts of Belarus in which the level of contamination by cesium was less than 37 kBq/m^2, the 3rd group – all territory of Gomel and Mogilev oblasts (oblast centers excluded), not taking the level of radioactive contamination into account, the 4th group – control for the 3rd group - all territory of Minsk and Vitebsk oblasts (without the capital and oblast centre of Vitebsk oblast).

It is easy to see from Figure 1 that while the initial prevalences of anomalies in both groups are practically equal, during the first three years after the Chernobyl disaster the prevalence of SR CA is much higher in the first group than in the control.

Figure 1. Prevalence of SR CA in 17 contaminated (Zone of Strict Radiological Control, ZSRC) districts (N=982) and 30 control districts of Belarus (N=1876)

After these three years, the prevalence of anomalies in two compared regions was not statistically different, but there existed an annual smooth growth, and during 1990-2003 the level of prevalence of investigated anomalies in both groups reached the level that was observed in the most contaminated districts (Table 2) between 1987-1989.

Table 2. Prevalence of SR CA in ZSRC and control districts during three periods (1981-1986, 1987-1989, 1990-2003)

Districts	Contaminated districts of ZSRC (N=17)			Control districts (N=30)		
Years	**1981-1986**	**1987-1989**	**1990-2003**	**1981-1986**	**1987-1989**	**1990-2003**
Number of liveborns and stillborns	58128	23925	72143	98522	47877	153680
Total number of **SR CA**	237	187	558	430	239	1207
Prevalence (1:1000)	4.08	7.82*	7.73	4.36	4.99	7.85

When prevalence of SR CA is compared on regional (oblast) level in the groups 3 and 4, there could be seen a trend to increased prevalence of anomalies during the first 3 years, bur this rise was not as distinctive as in zones of maximum contamination.

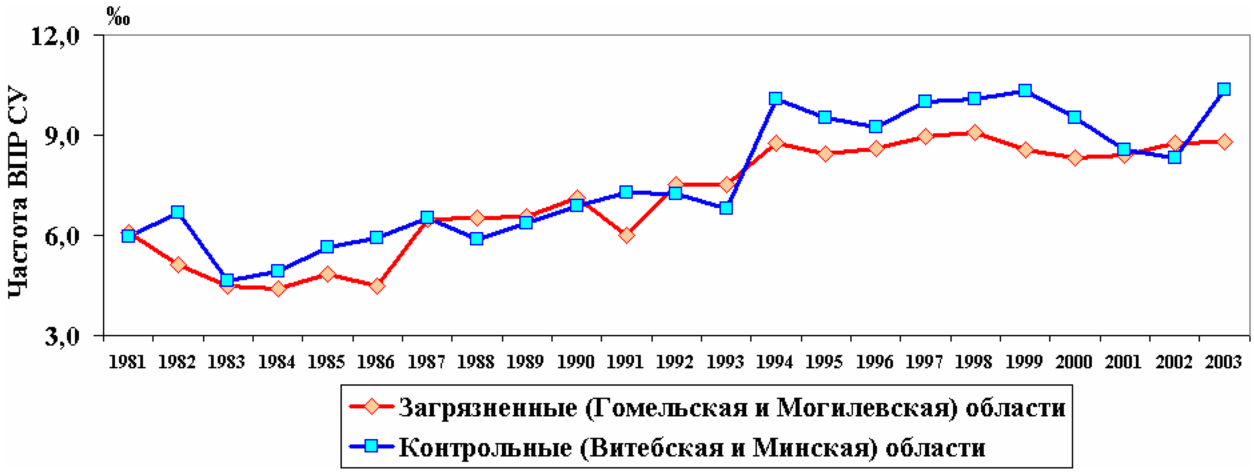

Figure 2 - Prevalence of SR CA in contaminated (Gomel, Mogilev; N=5692) and control (Vitebsk, Minsk; N=10008) oblasts.

The reason for a less clear 3-year rise of SR CA prevalence on oblast level as compared with the results obtained for districts, apparently is a "diluting" of the results of 17 districts severely contaminated by Chernobyl fallouts (with soil contamination by ^{137}Cs of 555 kBq/m^2 and more) by material obtained from other districts of the same oblasts where population lives on territories with low contamination or relatively clean areas. Moreover, there were territories in Minsk oblast (4th group) with soil contamination that exceeded 185 kBq/m^2.

Relative risk of SR CA for 17 most severely contaminated districts of Gomel and Mogilev oblasts increased from 0.9 in 1981-1985 to 1.6 in 1987-1989. After that (in 1990-2003) the relative risk fell to 1.0. The clearest increase, and hence the higher relative risk, was observed for polydactyly, limb reduction defects and multiple congenital anomalies. Significant input of dominant mutations, for which ionizing radiation is believed to be important, is characteristic for these anomalies. Summing up, in the most contaminated by Chernobyl fallouts regions of Belarus a three-year (1987-1989) increase in prevalence of CA was observed. In the following years the prevalence of CA increased in all areas indiscriminately to the level of contamination and there was practically no difference between "clean" and contaminated regions. Thus, if investigations of the prevalence of CA in Belarus were started 4-5 years after the Chernobyl disaster, as it happened in Japan after the nuclear bombardment, the difference between prevalence of CA in contaminated and non-contaminated zones would not have been detected.

4. RESULTS OF INVESTIGATION OF THE CONSEQUENCES OF CHROMOSOME AND GENOME MUTATIONS

As it was demonstrated by numerous investigations, the irradiation of population by radioactive fallouts of Chernobyl has induced an increase of mutations level in somatic cells (I.Eliseeva, 1991, M.Pilinskaya, S.Dybinskiy, 1992; G.Lazjuk et al,1995). It's not impossible that commeasurable changes did occur in gametal cells, but there are no investigations of this potential aftermath oft the Chernobyl disaster. Indirect assessment might be conducted by usage of the National Research Institute for Hereditary and Inborn Diseases results of investigation of prevalence of births with Down syndrome and prevalence of chromosomal diseases caused by non-balanced structural changes of chromosomes before and after Chernobyl period.

4.1. Investigations of prevalence of Down syndrome revealed that while variations of annual prevalence were in general low (about 1 case per 1000 births throughout the country and slightly higher variation in individual oblasts). In January 1987 a high increase (by the factor of 2.5) of births with Down syndrome was observed in Belarus. In Gomel oblast this factor reached its maximum – 3,6‰. These prevalences of Down syndrome were 2-3 times higher than expected (Table 3).

Table 3. – Territorial distribution of children with Down syndrome born in January 1987.

Region	Prevalence (‰)		O	E	O/E	95% CI	
	January 1987	1981-1989					
Belarus	2.5	1.0	31	13.9	2.2	1.5	3.2
Gomel oblast	3.6	1.1	8	2.6	3.1	1.4	6.2
Minsk oblast	3.1	1.1	6	2.2	2.8	1.0	6.0
Minsk city	2.7	1.1	6	2.6	2.3	0.9	5.1
Vitebsk oblast	2.2	1.0	4	1.8	2.1	0.6	5.7
Grodno oblast	1.7	0.9	3	1.6	1.9	0.2	4.6
Mogilev oblast	1.2	0.9	2	1.5	1.3	0.2	4.9
Brest oblast	1.0	0.8	2	1.8	1.1	0.1	4.0

Notes:
O – observed number of Down syndrome cases
E – expected number of Down syndrome cases
CI – confidence interval

Investigation of possible reasons for abrupt increase in the prevalence of Down syndrome (G.Lazjuk et al, 2002; G.Lazjuk et al, 2003) allowed for ruling out such factors as a change of mothers' age at birth, prenatal diagnostics and possible effect of increased (due to extraordinary situation) attention to this anomaly. After numerous discussions of these results it was defined that the only reason is an impact of short-term intensive irradiation of Belarus women's gametes. This conclusion is supported by the time period when the increase appeared (9 months after irradiation, when babies conceived in the period of the maximum increase of radiation were due to be born); by territorial distribution of numbers of such babies, which resembles a trajectory of air masses during first days after the accident; and by a known high radiosensitivity of mammals at the stage of ovogenesis preceding conception, which coincided with the maximum level of irradiation.

4.2. Investigation of frequencies of chromosomal diseases caused by sporadic structural changes of chromosomes

One of causes of chromosomal diseases is non-balanced sporadic structural changes of chromosomes (sporadic chromosomal aberrations - SCA). Such chromosomes could be found in gonads of parents (SCA de novo) or more remote ancestors (inherited SCA). By observing changes of the ratio SCA *de novo* to SCA inherited it is possible to estimate the pressure of mutagenic factors, including ionizing radiation, on hereditary structures.

Investigation of the ratio of SCA *de novo* to SCA inherited in the contaminated and the control zones before and after the Chernobyl disaster was carried out at the National Research Institute for Hereditary and Inborn Diseases of Belarus. For this purpose material of the Belarussian National Registry of congenital anomalies collected in 1979-1998 was used. Altogether, 209 families with various chromosomal diseases caused by SCA were examined. Of them, such children were born in 72 families before the Chernobyl disaster, and in 173 – after. As follows from Table 4, during the pre-Chernobyl period there was no statistical difference ($t=0.9$; $P=0.58$) between ratios of SCA *de novo* to SCA inherited in two compared regions. The ratio of inherited SCA to SCA *de novo* in families which had children with same diseases during 1987-1998 period shifted in favor of SCA *de novo* both in the contaminated and the "clean" zones, but the increase in the contaminated zones was more significant (89% and 68%, respectively, where $t=2.99$; $P<0.01$).

Table 4 – Comparison of sporadic (de novo) and inherited structural changes of chromosomes in children with chromosomal diseases in Belarus

Years of birth	Zones contaminated by radionuclides			Zones free from radionuclide contamination			Total
	de novo	inherited	total	de novo	inherited	total	
1979-1986	11(61%)	7	18	28(52%)	26	54	**72**
1987-1998	24(89%)	3	27	75(68%)	35	110	**137**
1979-1998	**35**	**10**	**45**	**103**	**61**	**164**	**209**

Thus, in spite of the fact that the presented data need more wide population investigations, already obtained data that the ratio of SCA *de novo* to SCA inherited has changed in favor of SCA *de novo* support the assumption that the pressure of mutagenic factors on hereditary structures increases, which is even more visible in zones with high contamination by Chernobyl fallouts.

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Doses of the Whole Body Irradiation in Belarus As a Result of the Chernobyl Accident

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Abstracts An assessment of the collective and mean individual doses of the whole body irradiation as a result of the Chernobyl accident for children, adults and total population of Belarus are described in the present report. The assessment was carried out on the basis of data on the surface contamination of Belarus and empirical data on contribution of internal exposure to the total irradiation of the whole body. It was found that in case the mixed population of Belarus collective and individual doses achieve some plateaus after 1990. The mean value of the collective dose of the mixed population in the period 1986-2004 is about $2.3 \cdot 10^4$ person-Sv. The mean individual dose of the whole body irradiation of the Belarusian population in this period of time is about 2.3 mSv. In case of the childhood population the whole body irradiation doses decrease since 1990. As a result of this decrease, collective and population doses of children of Belarus decrease to some fractions of background irradiation doses at 2004. The different temporal patterns of the whole body irradiation of different Belarusian subpopulations are determined by demographic factors such as birth, achieving of a definite age by children, death and external and internal migration.

Materials and Methods.

Assessment of the whole body irradiation doses was carried out on the basis of normalized doses of the whole body irradiation. The normalized doses are based on using normalized exposition doses in free air, $P_\gamma(t)$ that is a function of radioactive contamination of territory. The following expression determines normalized doses:

$$h^*(t) = \mu^{-1} \cdot C_1 \cdot C_2 \cdot F_1 \cdot \left[F_2 + (1 - F_2) \cdot F_3\right] \cdot P_\gamma(t). \qquad (1)$$

Here, $h^*(t)$ - the normalized equivalent dose delivered to the whole body at the time t,

μ - the contribution factor of external irradiation to the total dose,

C_1 - the conversion factor for transfer from exposition dose to tissue-absorbed dose,

C_2 - the conversion factor for transfer from tissue-absorbed dose to equivalent dose,

F_1 - the correction coefficient (considers different factors that can influence the exposition dose in air, for example such as soil cultivation etc.),

F_2 - the outdoor occupancy factor (fraction of time spent outside buildings),

F_3 - shielding factor of buildings,

$P_\gamma(t)$ -the exposition dose in a free air at the height 1 meter above the ground at the time t estimated for contamination level in the isotope ^{137}Cs equal to 37 kBq/m^2 at the end of April 1986.

Data on exposition doses in free air assessed in the report [1] for so-called “caesium spot” were used in the present report for calculation of normalized doses. They were estimated for real composition of radionuclides deposited in Belarus as a result of the Chernobyl accident [2]. In the process calculating $P_\gamma(t)$ values, all radionuclides that gave some measurable contribution to the total exposition in 1986 were considered [1]. They are ^{131}I, ^{132}Te, ^{103}Ru, ^{106}Ru, ^{140}Ba, ^{134}Cs and ^{137}Cs. According to data [1] the short-lived isotopes ^{131}I, ^{132}Te, ^{103}Ru, ^{106}Ru, ^{140}Ba and ^{134}Cs determined approximately 85% of the summary exposition dose in the period from 26 April 1986 to 31 August 1986, while approximately 20% in the period from 26 April 1986 to 31 December 1986. The isotope ^{137}Cs was taken after the accident at the Chernobyl NPP as an indicator of the radioactive contamination. Therefore, only this isotope is mentioned here and below by characterizing of radioactive contamination despite the fact that contribution of other isotopes to irradiation doses is also included.

Individual dose at any arbitrary level of radioactive contamination of territory can be assessed by using of the formula:

$$h(t) = \frac{A_0^{137}}{37} \cdot h^*(t). \qquad (2)$$

Here, $h(t)$ is the equivalent dose of the whole body irradiation on the territory with contamination in the isotope ^{137}Cs equal to A_0^{137} kBq/m^2 at the end of April 1986 delivered at the time *t*. It is the arithmetic mean dose of the whole body irradiation of population living on the territory contaminated with the isotope ^{137}Cs to the level A_0^{137} kBq/m^2. This is the mean individual dose for this territory. Multiplication of $h(t)$ with the number of irradiated persons gives the collective equivalent dose of the whole body irradiation delivered at the time *t*:

$$H_t^{Coll} = h(t) \cdot N_t . \qquad (3)$$

The total collective dose of irradiation delivered to the whole body during some time period can be determined by summing data estimated with the formula (3). It is to be noticed here that in case of long-term irradiation some special procedure has to be used for correct estimation of the collective doses received by irradiated population for some time period. The use of direct summing of data estimated on the basis of the formula (3) can cause a significant overestimation of the collective dose delivered in some finite time. Data on population numbers given in statistical handbooks [3-6] were used in the present report by estimation of collective doses.

Results and discussion.

Irradiation doses.

All contaminated territories in Belarus were divided after the accident at the Chernobyl NPP in clean territories, characterized by contamination level in ^{137}Cs at the end of April 1986, A_0^{137}, less than 37 kBq/m^2 (1 Ci/km^2), and contaminated territories, characterized by contamination level in ^{137}Cs equal or higher than 37 kBkBq/m^2 (1 Ci/km^2) [7]. Contaminated territories in Belarus were then divided in following categories: 37 ≤ A_0^{137} ≤ 185 kBq/m^2, 185 ≤ A_0^{137} ≤ 555 kBq/m^2, 555 ≤ A_0^{137} ≤ 1,480 kBq/m^2, A_0^{137} > 1,480 kBq/m^2.

Table 1 gives annual total (external plus internal) individual dose of the whole body irradiation of rural inhabitants living in areas with these levels (fourth, fifth and sixth column) and specific values of contamination. The second column is doses of irradiation of rural inhabitants living in areas with the contamination level in ^{137}Cs equal to 3.7 kBq/m^2, which is approximately the same contamination with ^{137}Cs existed in Belarus before the Chernobyl accident. It was resulted from the atmospheric test of atomic weapon [8]. The third column of Table 1 gives the mean individual doses of the whole body irradiation for the territory with the contamination level equal to 37 kBq/m^2 or normalized doses assessed for rural inhabitants of Belarus.

Table 1. Annual mean individual equivalent doses of the whole body irradiation of rural inhabitants of Belarus (mSv/a).

Year	Level of ^{137}Cs contamination, kBq/m^2 (*Ci/km^2*)					
	3.7 (*0.1*)	37 (*1*)	37-185 (*1-5*)	185-555 (*5-15*)	555-1,480 (*15-40*)	1,480 (*40*)
1986	0.0972	0.9719	2.896	8.339	23.62	51.22
1987	0.0468	0.4681	1.395	4.016	11.37	24.67
1988	0.0296	0.2957	0.8812	2.537	7.186	15.58
1989	0.0181	0.1806	0.5382	1.549	4.388	9.517
1990	0.0104	0.1042	0.3104	0.8938	2.531	5.490
1991	0.0089	0.0885	0.2639	0.7597	2.152	4.666
1992	0.0079	0.0772	0.2302	0.6628	1.877	4.071
1993	0.0069	0.0686	0.2043	0.5883	1.666	3.614
1994	0.0062	0.0621	0.1849	0.5324	1.508	3.270
1995	0.0057	0.0570	0.1698	0.4890	1.385	-
1996	0.0053	0.0531	0.1583	0.4556	1.290	-
1997	0.0049	0.0495	0.1475	0.4247	1.203	-
1998	0.0047	0.0469	0.1397	0.4021	1.139	-
1999	0.0044	0.0443	0.1319	0.3799	1.076	-
2000	0.0043	0.0425	0.1267	0.3647	1.033	-
2001	0.0041	0.0405	0.1206	0.3472	0.983	-
2002	0.0039	0.0389	0.1160	0.3339	0.946	-
2003	0.0038	0.0382	0.1138	0.3277	0.928	-
2004	0.0036	0.0362	0.1078	0.3104	0.879	-
1986-2004	0.2764	2.7639	8.2364	23.7141	67.162	110.555

Conversion factors C_1 and C_2 used for assessment of normalized doses were taken from the report [9]. The coefficient F_1 = 0.368 was accepted for the period 1990-2004. This value was assessed in the report [1] on the basis of empirical data. For the period 1986-1990, the value of the factor F_1 was assumed to linearly change from 1 to 0.368. The coefficient F_2 equal to 0.295 was accepted as the occupancy factor of rural inhabitants of Belarus [10,11]. The value of shielding factor for rural inhabitants in Belarus was taken equal to 0.212. It was also assessed on the basis of empirical data [1]. The coefficient μ characterizing contribution of the external irradiation equal to 0.736 was used in assessments. This value was assessed on the basis of empirical data given in the report [12].

Estimation of mean individual doses of rural inhabitants living in territories with contamination levels 37-185, 185-555 and 555-1480 kBq/m^2 (fourth, fifth and sixth columns of Table 1) was performed on the basis of respective average contamination levels. They are 110.2, 317.5 and 899.1 kBq/m^2, respectively, at the end of April 1986. These values were estimated on the basis of data given in the report [1] on the basis of empirical data [13].

Data given in the sixth column of Table 1 allow to assess the individual dose of the whole body irradiation accumulated in the period 1986-1995 for persons living in the area with the level of contamination 555-1480 kBq/m^2. It is 57.7 mSv.

The Russian specialists [14] estimated the cumulative dose of the whole body irradiation of rural inhabitants lived in 1986-1995 in territories with the same level of contamination equal to approximately 60 mSv. This is practically the same as irradiation dose estimated for rural inhabitants of Belarus living in the area with the level of contamination 555-1480 kBq/m^2.

A very good agreement in data assessed for the Belarusian rural inhabitants and data estimated by the Russian specialists [14], which used more sophisticated model, justifies the simplified method of the whole body irradiation described in the present report.

As can be seen from Table 1, assessment of irradiation doses for inhabitants of the territory with the level of contamination 1,480 kBq/m^2 was performed only for the period 1986-1994. This was because all residents of territories contaminated with 1,480 kBq/m^2 and higher were resettled to clean areas in Belarus in 1990-1994 [15]. According to our assessment, the mean individual dose accumulated by them before resettlement is approximately 100 mSv.

Data presented in Table 1 show that mean arithmetic individual doses of the whole body irradiation of rural inhabitants of Belarus accumulated in 1986-2004 vary from some fractions of millisivert to hundreds of millisivert. In some cases inhabitants of the Belarusian rural settlements accumulated much higher doses of the whole body irradiation for much shorter periods of time. Assessment made on the basis of the method described in this report gives for inhabitants of the rural settlement Vysoki Borak the population dose of the whole body irradiation equal to 135 mSv. This dose was accumulated in the period 1986-1990. The population dose of the whole body irradiation in the same period in case of inhabitants of the rural settlement Chudzyany is approximately 295 mSv. The settlement Vysoki Borak is situated in the Krasnopolie district of the Mogilev region approximately 230 kilometers from the Chernobyl NPP. The settlement Chudzyany is situated in the Cherikov district of the Mogilev region approximately 250 kilometers from the Chernobyl NPP. The average contamination of the settlement Vysoki Borak was 2,480 kBq/m^2 and of the settlement Chudzyany 5,420 kBq/m^2 [13].

It is well known that maximum individual doses often exceed the mean dose by a factor of 3-5 [16]. This means that some inhabitants of the rural settlement Chudziany received doses of the whole body irradiation up to 1,500 mSv. In this respect they are comparable with atomic bomb survivors.

Table 2 presents collective doses of rural and urban inhabitants of Belarus in 1986-2004, collective doses of the total population of Belarus (sixth column) as well as mean individual doses of the whole body irradiation of the entire Belarusian population in this period (seventh column). The data in the seventh column of Table 2 were calculated by dividing the data given in the sixth column by the total population of Belarus.

The following simplified method was used for assessment of data presented in Table 2. The entire Belarusian population was divided into two subpopulations: rural and urban subpopulations. Normalized doses of the whole body irradiation of rural and urban subpopulations were assessed separately for these two subpopulations. In case of rural subpopulation the same values of coefficients F_2 and F_3 as in previous assessment (Table 1) were taken. For assessment of the normalized doses for urban inhabitants of Belarus coefficient F_2 equal to 0.2 and coefficient F_3 equal to 0.1 were used [11].

Calculation of population doses for urban subpopulation was performed for an average contamination of the Belarusian territory equal to 78.42 kBq/m^2. This value was estimated from the total amount of the ^{137}Cs isotope deposited in Belarus [1]. Values of collective doses of the urban population of Belarus were calculated for the average contamination equal to 37 kBq/m^2 [11].

Table 2. Annual normalized and collective irradiation doses of the Belarusian population as a result of the Chernobyl accident.

Year	Rural population		Urban population		Total Population	
	Normalized dose, mSv	Collective dose, PSv	Normalized dose, mSv	Collective dose, PSv	Collective dose, PSv	Individual dose, mSv
1986	0.9719	7,749	0.6133	3,818	11,567	1.1583
1987	0.4681	3,732	0.2954	1,839	5,571	0.5547
1988	0.2957	2,358	0.1866	1,162	3,520	0.3489
1989	0.1806	1,440	0.1140	709	2,149	0.2117
1990	0.1042	617	0.0657	409	1,026	0.1007
1991	0.0886	491	0.0559	348	839	0.0823
1992	0.0773	400	0.0488	303	703	0.0689
1993	0.0686	330	0.0433	269	599	0.0585
1994	0.0621	275	0.0392	244	519	0.0507
1995	0.0570	232	0.0360	224	456	0.0447
1996	0.0531	216	0.0335	209	425	0.0418
1997	0.0495	201	0.0312	194	395	0.0389
1998	0.0469	191	0.0296	184	375	0.0372
1999	0.0443	180	0.0279	174	354	0.0352
2000	0.0425	173	0.0268	167	340	0.0339
2001	0.0405	165	0.0255	159	324	0.0324
2002	0.0389	158	0.0246	153	311	0.0313
2003	0.0382	156	0.0241	150	306	0.0309
2004	0.0362	147	0.0228	142	289	0.0293
1986-2004	2.7639	19,211	1.7442	10,857	30,068	2.9900

Data presented in the sixth column of Table 2 gives for the period 1986-1995 the collective dose of the whole body irradiation as a result of the Chernobyl accident 26,949 PSv. This value is by 28,7% higher than the collective doses assessed for Belarus for the same period in the report [12]. The authors [12] carried out detailed study of irradiation doses in different regions of Belarus and estimated the total collective dose of the whole body irradiation of the Belarusian population equal to 20,940 PSv. However, they studied only inhabitants of rural and urban settlements situated in territories with the contamination level with ^{137}Cs equal or higher than 37 kBq/m^2. On the contrary, data shown in Table 2 were assessed for all contaminated territories of Belarus. Our assessment included also areas with the contamination level less than 37 kBq/m^2. Additionally, the method of assessment described in the present report considered also on an indirect way the irradiation of persons that worked as liquidators in the 30-km zone in 1986-1989. This was done by including radioactive nuclides deposited in the Belarusian part of the 30-km zone for the estimation of the average contaminated level in case of rural inhabitants of Belarus. Excluding of the 30-km zone as well as areas contaminated to levels less than 37 kBq/m^2 gives practically the same collective dose as it was estimated by authors [12].

The very good agreement between the data assessed in this report and the data estimated in reports [12,14] allows to conclude that reliable data characterizing irradiation of affected inhabitants of Belarus are established.

Data in the sixth and seventh column of Table 2 can be used for estimation of cumulative collective and individual doses of the whole body irradiation of the Belarusian population for any period of interest. Direct summing of data presented in these columns, however, does not give correct doses unless two opposite processes for dose accumulation are taken into consideration. The first process is positive accumulation of irradiation doses year by year. The second process is loosing of already delivered doses as a result of demographic processes. The influence of demographic processes can be demonstrated for irradiation of the Belarusian population in 2004. According to the data of Table 2, the collective dose of the whole body irradiation of the Belarusian population in 2004 was approximately 289 person-Sv. The cumulative mean individual dose for the period 1986-2004 was 2.99 mSv (seventh column of Table 2). 140,064 persons died in Belarus in this year. It is well known that older people give the main contribution to the mortality in each country. Therefore it is possible to assume that all people that did in Belarus were alive at the time of the Chernobyl accident. This means that the individual dose accumulated by persons who died in 2004 is practically the same as the cumulative the dose delivered in the period 1986-2004, which is 2.99 mSv (seventh column of Table 2). Multiplying of this value with a number of people that died in 2004 gives the collective dosed loosed by the Belarusian population in 2004 equal to 418.8 persons-Sv. This is by 129.8 person-Sv larger than that delivered to the whole Belarusian population in 2004.

The influence of demographic processes on the cumulative irradiation doses can be much more significant in case of "truncated" populations that include persons with some definite age. The population of children gives an example of such populations. It contains only persons at the age less than 15 years. Consequently, the children's subgroup in 2004 contained only children who were born after 1989 when doses of the whole body irradiation in Belarus were much lesser than in 1986-1989. The loosing of high-

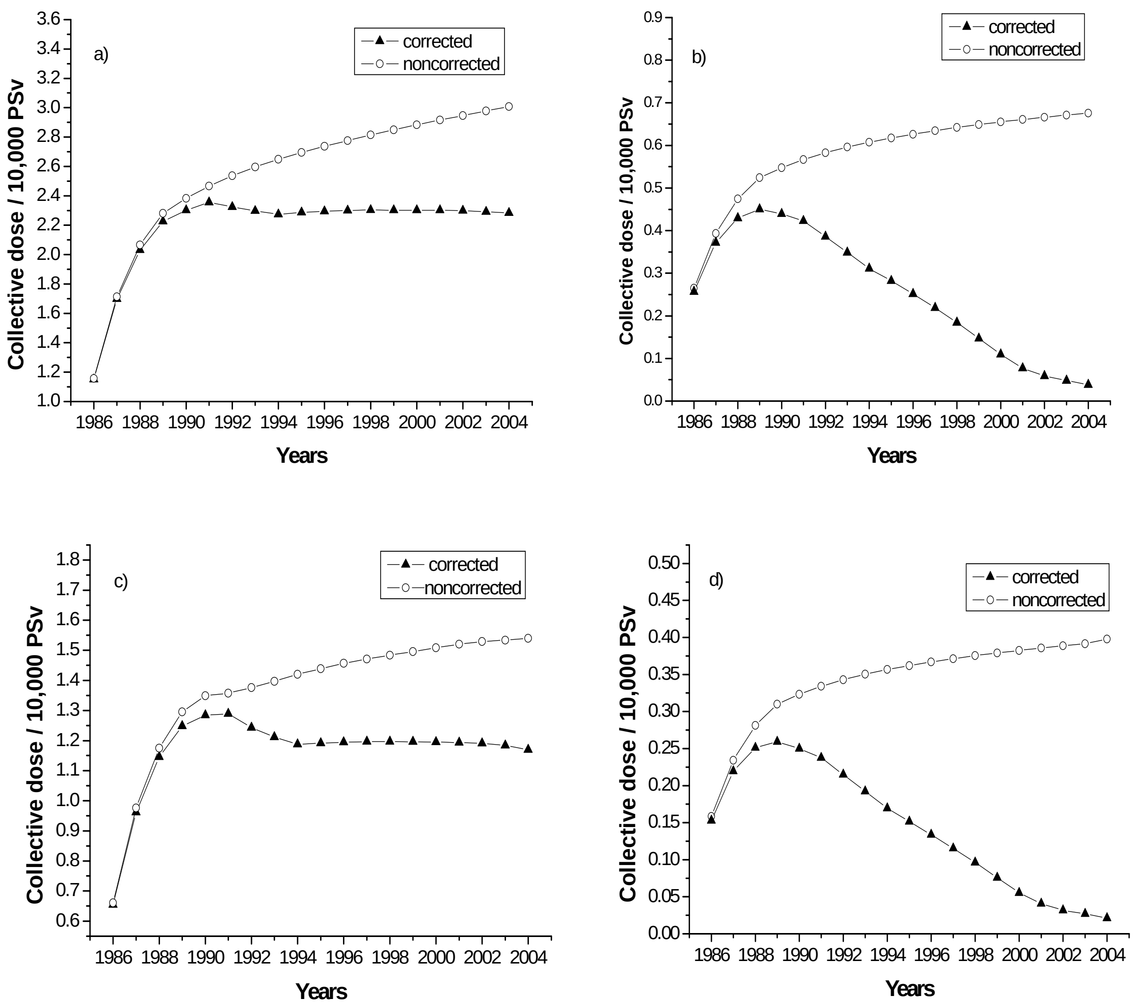

Fig.1. Collective equivalent doses of the whole body irradiation in Belarus as a result of the Chernobyl accident: a) total population of Belarus, b) children of Belarus, c) total population of the Gomel region, d) children of the Gomel region.

irradiated children decreases the cumulative doses of the subgroup of children.

As can be seen from here, different concepts of cumulative doses have to be distinguished in case of chronic irradiation. The first concept is a cumulative dose that was delivered to the population living on some contaminated territory. In the second concept, cumulative dose was possessed by the population during certain time when they live on some contaminated territory. In the first concept one needs only to determine the sum of doses delivered in the period of interest. In the second concept, cumulative doses of irradiation are some functions of time one needs to take into account about demographic processes. Fig.1 and Fig.2 demonstrate collective and population doses of irradiation of the entire Belarus and of the Gomel region assessed for these two different concepts.

In case of the Gomel region the same method of assessment as in case of the entire Belarus was used in estimation of the data presented in Fig.1 and Fig.2. It was also assumed that normalized doses of the whole body irradiation are the same for children as for adolescents and adults.

Figure 1 demonstrates influence of demographic processes on collective doses of the whole body irradiation of the entire population of Belarus as a result of the Chernobyl accident. The subscript “corrected” in Fig.1 refers to data assessed by considering of demographic processes mentioned above. The subscript “noncorrected” denotes in case of the entire Belarus data assessed by simple summing up values presented in Table 2.

The influence of the natural demographic processes on mean individual doses of Belarus and the

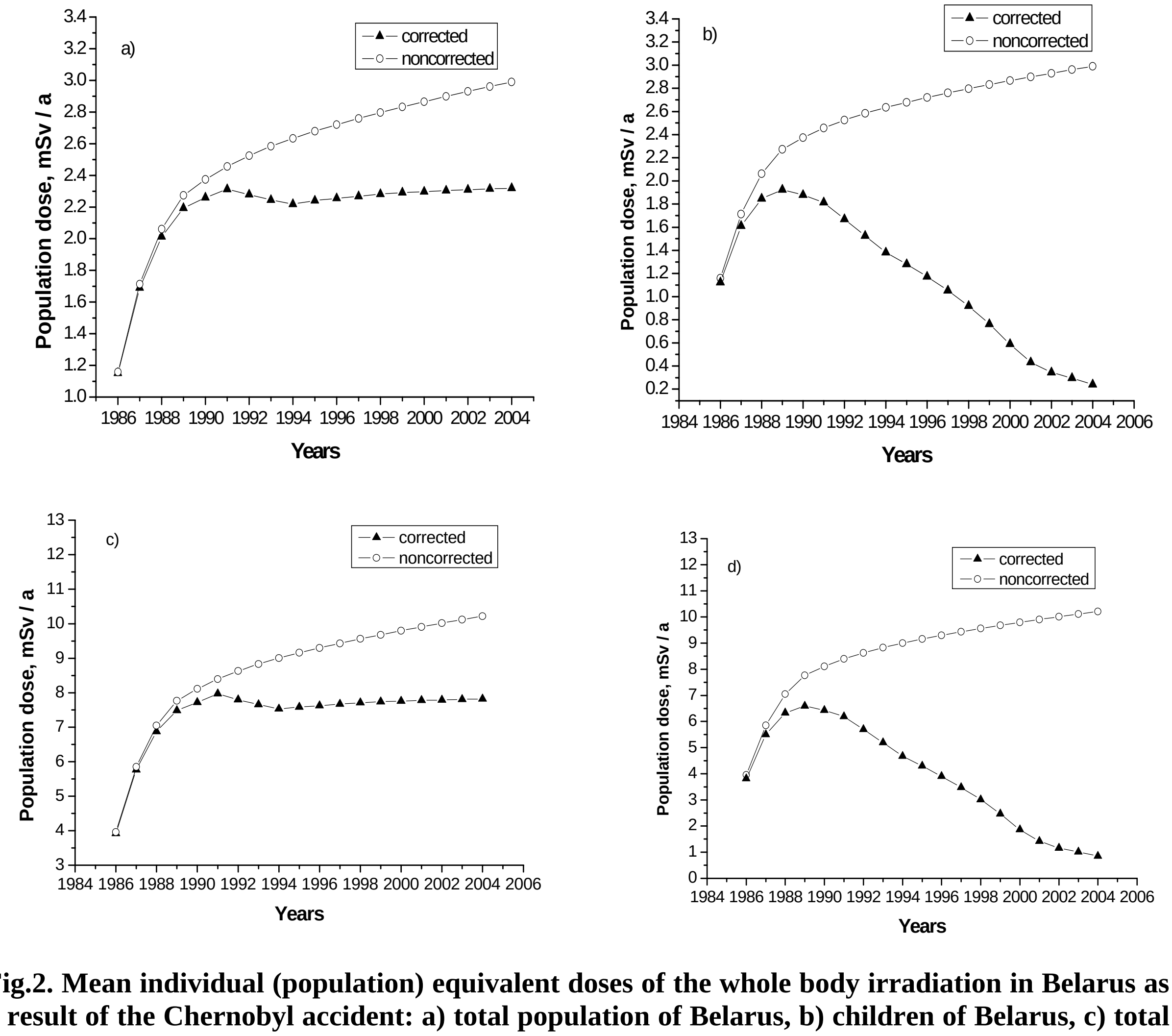

Fig.2. Mean individual (population) equivalent doses of the whole body irradiation in Belarus as a result of the Chernobyl accident: a) total population of Belarus, b) children of Belarus, c) total population of the Gomel region, d) children of the Gomel region.

Gomel region is shown on Fig.2.

As can be seen from Fig. 1, collective doses of the whole body irradiation in case of total populations of Belarus as well as the Gomel region increase up to 1991 and then remain practically constant showing some plateaus in the time period 1991-2004. Our assessment shows that the same temporal patterns demonstrate also collective doses of the whole body irradiation of entire populations of other regions of Belarus.

On the contrary, “noncorrected” collective equivalent doses in case of total populations of Belarus and the Gomel region demonstrate the further increase after 1990 although it is much slower than in 1986-1990. Comparison of “corrected” and “noncorrected” collective doses assessed for the entire population of Belarus as well as for the Gomel region shows that “noncorrected” collective doses in 2004 are by approximately 20% higher than “corrected” doses. This difference correlates with number of people that died in the period 1987-2004. Assessment on the basis of statistical handbooks [5,6] shows that 2,239,782 persons died in Belarus in this period. This is about 22.7% from the total number of the Belarusian population averaged for the period 1987-2004 (approximately 10,000,000 persons).

Quite different situation arises in case of children’s population. Here “corrected” collective equivalent doses increases up to 1989 and then decreases rapidly to very small values after 2000. For example, “corrected” collective equivalent doses of children’s populations of Belarus and the Gomel region in 2004 were by one order in magnitude less than in 1989. Such significant decrease of collective doses resulted from the “loss” of persons who were children in 1986-1989 and left the children’s population before 2004 as a result of their transition to the population of adolescents and adults.

The same temporal patterns demonstrate mean individual doses of the whole body irradiation, which can be seen on Fig.2. Such temporal patterns of irradiation doses of children indicate that possible medical effects of the Chernobyl accident in children have to be expected only immediately after this accident. Table 3 contains cumulative collective and population doses of the whole body irradiation assessed for children, adults and the mixed population of Belarus for the period 1986 –2004 by considering the described correction procedure.

Table 3. Collective and mean individual doses of the whole body irradiation of different subgroups in Belarus as a result of the Chernobyl accident.

Year	Children doses		Adults doses		Whole population	
	Collective	Individual	Collective	Individual	Collective	Individual
	/10^4 PYSv	mSv	/10^4 PYSv	mSv	/10^4 PYSv	mSv
1986	0.2569	1.1220	0.8936	1.1567	1.1505	1.1520
1987	0.3722	1.6107	1.3255	1.7091	1.6977	1.6905
1988	0.4297	1.8457	1.6014	2.0545	2.0311	2.0130
1989	0.4501	1.9230	1.7767	2.2691	2.2267	2.1934
1990	0.4396	1.8772	1.8633	2.3744	2.3029	2.2602
1991	0.4228	1.8132	1.9334	2.4591	2.3562	2.3123
1992	0.3863	1.6696	1.9380	2.4523	2.3243	2.2791
1993	0.3489	1.5254	1.9490	2.4509	2.2978	2.2452
1994	0.3109	1.3818	1.9624	2.4600	2.2733	2.2192
195	0.2821	1.2804	2.0056	2.5097	2.2876	2.2404
1996	0.2516	1.1723	2.0438	2.5504	2.2953	2.2554
1997	0.2192	1.0531	2.0820	2.5907	2.3011	2.2689
1998	0.1843	0.9197	2.1196	2.6279	2.3038	2.2826
1999	0.1471	0.7631	2.1556	2.6595	2.3027	2.2923
2000	0.1097	0.5898	2.1926	2.6921	2.3023	2.2979
2001	0.0771	0.4318	2.2252	2.7187	2.3023	2.3045
2002	0.0588	0.3445	2.2400	2.7260	2.2988	2.3102

Assessment on the basis of data presented in the sixth column of Table 3 gives for the period 1990-2004 the mean time-averaged collective dose of the whole body irradiation of the Belarusian population as a result of the Chernobyl accident equal to $2.3 \cdot 10^4$ person-Sv. Data shown in the seventh column of Table 3 gives as the mean time-averaged mean individual dose of the whole body irradiation for this period equal to 2.28 mSv.

It is evident that the described method of correction can not give fully correct doses of the whole body irradiation because it does not take in account other important factors that influence the accuracy of assessed values. Significant influence on the correctness of dose assessment has internal (movement to other regions of Belarus) and external (movement to other countries) migration of inhabitants of contaminated areas. It began soon after the Chernobyl accident. As a result, a large fraction of people migrated from territories affected by the Chernobyl accident. For example, one sixth of inhabitants of the Slavhorod district (Mogilev oblast) left their contaminated settlements during the first three years after the accident [17]. The similar situation arose in other contaminated districts of the Mogilev oblast. The process of migration was even more pronounced in contaminated areas of the Gomel oblast [18].

According to the official information, the number of people that changed their place of residence in borders of Belarus in 1986-2000 reached 1,500,000, while the averaged total number of people in this period in Belarus equal to 10 millions. 675.1 thousand of people migrated in 1990-2000 from Belarus to other countries of the world. Out of this number, 524 thousand of people migrated to countries of the Community of Independent States (CIS) and 151.1 thousand of people immigrated to countries beyond the bounds of the former USSR. For example, approximately 130 thousand of persons of the Jewish nationality immigrated to Israel from the contaminated areas in Belarus and the Ukraine [19]. About 50% persons from this number have immigrated to Israel from Belarus.

The internal migration from the contaminated areas of Belarus was occurring with a partial assistance of the state. On this way approximately 135,000 persons had left the territories strongly affected by the Chernobyl accident with the support of the state [20]. About 200,000 persons migrated from contaminated areas without assistance of the state [20].

The external and internal migration causes significant incorrectness in assessment of irradiation doses carried out by using the method based on contamination levels. The external migration decreases collective and population doses of the affected populations because of a transfer of irradiation doses to other countries. This transfer means a “loss” of radiation risk for Belarus. This means that using doses presented in Table 3 assessed without taking in account the loss of some fractions of doses will cause an underestimation of radiation risks.

The internal migration does not cause such underestimation of radiation risk because the transfer of irradiation doses between different regions of Belarus causes only leveling of radiation risk in different regions of Belarus. However, the internal migration causes decrease of statistical power of analysis because it disturbs the correlation between levels of contamination and incidence rates of analyzed diseases. The effect of internal migration can even exclude the possibility of using of standard method of analysis based on comparison of incidence rates in contaminated and not contaminated regions.

Conclusions

Collective and individual doses of the whole body irradiation of the Belarusian population were assessed on the basis of contamination of Belarus caused by the accident at the Chernobyl NPP. Assessment was carried for the period 1986-2004 years. The influence of such demographic factors as birth, achieving of the age 15 years by children as well as death was taken into account in course of assessment. Estimated results demonstrate that in case of children collective and individual doses increase in the period 1986-1989 and then decrease practically to fractions of collective and population doses of the background irradiation. The collective and individual doses in case of adults of Belarus demonstrate a significant increase in the period 1986-1989 and changed with some weak increase after 1990. The collective and individual doses of the whole population of Belarus increase in the period 1989-1989 and then remain practically constant up to 2004.

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Increase of Regional Total Cancer Incidence in North Sweden Due to the Chernobyl Accident?

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Abstract

Study objective. Is an increase of cancer incidence detectable in Sweden due the Chernobyl accident?

Design. The fallout of caesium-137 was studied in relation to the cancer incidence 1988-1996.

Setting. In Northern Sweden, affected by the Chernobyl accident in 1986, we categorised 450 parishes by caesium-137 deposition: <3 (reference), 3-29, 30-39, 40-59, 60-79 and 80-120 kBq/m^2.

Participants. All individuals 0-60 years of age and living in these parishes in 1986 were included i.e. 1 143 182 persons. In the follow-up 22 409 cancer cases were recorded in 1988-1996.

Main results. Controlling for age and various other factors, potentially to influence the result, the adjusted relative risks for the exposure categories were 1.00 (reference <3 kBq/m^2), 1.05, 1.03, 1.08, 1.10 and 1.21. The excess relative risk was 0.11 per 100 kBq/m^2 (95% CI 0.03;0.20). The cancer incidence rate differences between 1988-1996 and the reference period 1986-1987 in each category were 30.3, 36.8, 42.0,

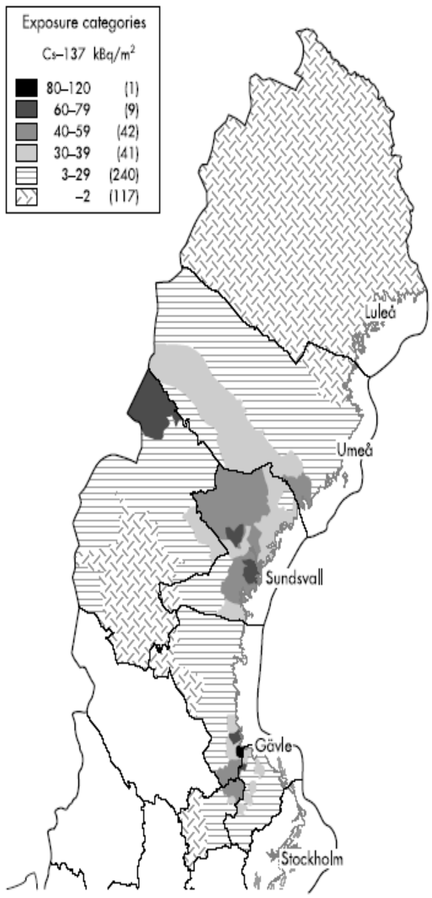

Figure 1. Parishes in the study area classified by ground deposition of caesium-137 and number of parishes in parentheses for each category. The map was originally produced by the Geological Survey of Sweden on behalf of the Swedish Radiation Protection Authority, here modified after permission from the latter.

45.8, 50.1 and 56.4 per 100 000 persons. No clear excess occurred for leukaemia or thyroid cancer.
Conclusions. A slight exposure-related increase in total cancer incidence has occurred in Northern Sweden after the Chernobyl accident.

Introduction

In Europe concerns about the consequences of the Chernobyl accident have focused on childhood malignancies, especially leukaemia, assumed to have a short latency period after irradiation. Several studies have been performed outside the former Soviet Union, but none has shown any clear relationship with the fallout from the Chernobyl accident. However, children exposed during pregnancy have shown an increased risk of leukaemia in Greece, Germany and Ukraine, but not in Belarus. A recent study from Ukraine reports an increase in adult leukaemia after exposure from Chernobyl radiation. In Belarus, Ukraine and the western part of Russia, there has been a dramatic increase in thyroid cancer incidence in children related to the accident. In other parts of Europe a similar increase in thyroid cancer has been seen in adults.

Five percent of the released caesium-137 from the Chernobyl accident was deposited in Sweden due to heavy rainfall on 28-29 April 1986, mainly in the eastern coastal regions from Umeå in the North to Stockholm in the South. During the first weeks the main contributors to the radiation dose were short-lived nuclides replaced by long-lived caesium-134 and caesium-137 isotopes. The dose to the inhabitants, depending on place of residence, outdoor activity and dietary habits, ranged from 1-2 mSv to a maximum of about 4 mSv the first year.

Our investigation includes the population of seven counties with the highest fallout, all in Northern Sweden. There were also unaffected areas in these counties serving as internal reference areas. The South of Sweden was excluded as much less affected by the fallout, but also because of higher background cancer incidence rates, especially in the largest cities.

Methods

Out of Sweden's 21 counties, the seven counties included in this study were Norrbotten, Västerbotten, Jämtland, Västernorrland, Gävleborg, Västmanland and Uppsala County. These counties and some major cities are shown in Figure 1. All individuals in the population registry who were 0-60 years old in 1986 and who had the same address both on 31 December 1985 and 31 December 1987 were included in the study. Cancer cases and deaths along with date of diagnosis were retrieved from the Swedish Cancer Registry for 1986 to 1996. The follow-up period started on January 1, 1988 including 1 143 182 persons with information on age, sex and parish of residence during the two preceding years. Number of cancer cases during the follow-up 1988-1996 are given in Table 1.

By assignment with the Swedish Radiation Protection Authority, the Geological Survey of Sweden had performed aerial gamma-measurements over the entire Sweden from May to October 1986 resulting in a ground deposition map of caesium-137 in 12 different categories. Collapsing these categories, the population in the 450 parishes, i.e., the smallest administrative units of these seven counties, were classified into six exposure categories: <3, 3-29, 30-39, 40-59, 60-79 and 80-120 kBq/m^2 (Figure 1 and Table 1). The 117 parishes not affected (<3 kBq/m^2) in these counties served as reference areas.

The relative risks were adjusted by population density, smoking habits, socio-economic factors and cancer incidence in the parishes before the accident (1986-1987). The risk difference was calculated as the age adjusted cancer incidence during the follow-up (1988-1996) minus the cancer incidence in each exposure category before the Chernobyl accident (1986-1987). Hence, the relative comparison in incidence is within the column and the difference is a horizontal comparison of incidence before and after the Chernobyl accident.

Table 1. Number of individuals and cancer cases by exposure category. Adjusted relative risks by category in relation to the unexposed (reference category). Age standardised risk difference as incidence per 100 000 persons during the follow-up period 1988-1996, minus the incidence 1986-1987 for each exposure category, respectively. Statistical uncertainty expressed as confidence interval (95% CI) i.e. a relative risk above 1.00 and a risk difference above 0.00 is statistical significant, respectively.

Exposure kBq Cs-137/m²	Population 1 January 1988	Number of cancer cases 1988-1996	Relative risk (95 % CI)	Risk difference (95% CI)
<3	359 509	6 691	1.00 (reference)	30.3 (25.5-35.2)
3-29	527 812	10 378	1.05 (0.99-1.11)	36.8 (32.6-41.0)
30-39	92 323	1 827	1.03 (0.95-1.12)	42.0 (33.0-51.0)
40-59	124 862	2 744	1.08 (0.94-1.23)	45.8 (37.9-53.4)
60-79	21 625	401	1.10 (0.89-1.34)	50.1 (29.4-70.8)
80-120	17 051	368	1.21 (0.98-1.49)	56.4 (33.9-78.9)
Total number	1 143 182	22 409		

Results

The relative risk for all cancer sites showed a slight increase in all exposure categories using <3 kBq caesium-137/m^2 as the internal reference. As an average over the categories an excess relative risk of 0.11 (95% CI 0.03-0.20) per 100 kBq/m^2 was calculated. Because of an ageing population it was necessary to restrict the population to 5-59 years of age in order to obtain the risk difference corresponding to 13 823 cancer cases for the follow-up period. The risk difference of 30.3 per 100 000 persons in the reference category represents the underlying time trend i.e. the increase in cancer incidence not affected by the Chernobyl fallout (Table 1). Neither the relative risks, nor the risk differences could be explained by different smoking habits in the exposure categories. Radiosensitive neoplasms with assumed short latencies like leukaemia and thyroid cancer did not increase in relation to the radioactive fallout in North Sweden after the Chernobyl accident.

Discussion

Before the study we realized that if there would be a effect on the cancer incidence due to the Chernobyl accident it would only be a small such risk. Therefore we designed our study to be as sensitive as possible to catch such an increase, if existing. As many exposed counties as possible were included, small geographical areas (parishes) were used for assessing the exposure, we used a two year residence inclusion criteria as a considerable part of the dose from the Chernobyl accident was achieved during that time and finally we applied an age restriction i.e. an age span with expected low incidence of malignancies in general. A better exposure assessment would have been obtained if we could have traced the addresses of each individual during the follow-up period. However, most likely the majority of the population has continued to live in the same parish throughout the duration of the study.

Unless simply representing a chance phenomenon, the findings in our study are somewhat unexpected indicating a possible cancer effect of the Chernobyl fallout in North Sweden despite a short latency period and low degree of exposure. This is the first study suggesting a possible increase in total cancer incidence after the Chernobyl accident outside the former Soviet Union, let alone only a marginally increased risk. Out of the 22 409 cancer cases an estimated 849 cases could be attributed to the fallout from the Chernobyl accident. However, no less than 494 of these cases are derived from the second category 3-29 kBq/m^2. A slightly different classification of the reference categories would therefore dramatically influence the number of exposure-related cancer cases.

Using the estimated collective dose in Sweden of about 6 000 man-Sv during 50 years due to Chernobyl contamination, and the risk estimates given by the International Commission on Radiological Protection, the number of expected extra cancer deaths could be calculated to 300. Given a true effect, our study indicates that the risk from low dose irradiation might come earlier and be slightly higher than predicted by the International Commission on Radiological Protection estimates. The official risk estimate relies to a great extent on the follow-up of the atomic bomb survivors in Hiroshima and Nagasaki, but has been questioned because only those alive in 1950 were included in the study, hence ignoring early cancer cases.

A short latency period like in our study has been seen in other epidemiological studies on ionising radiation. Our findings of an increase of total cancer incidence in Sweden soon after the Chernobyl accident is therefore not a unique finding, but we have not been able to detect any specific cancer site responsible for our findings. An interpretation could therefore be that the ionising radiation might exert a late stage general promoting effect on cancer.

A larger problem is that the exposure assessment was based on the ground deposition of caesium-137 from the Chernobyl accident, not taking into account any internal dose contribution through food and inhalation. This is especially important in regions with relatively low ground deposition where a high intake of wild berries, mushrooms, game meat et cetera would give a higher internal than external dose from caesium-137. Restrictions in food intake due to governmental regulation are likely to have led to lower doses, especially in higher exposed areas, hence lowered the radiation-induced cancer risks for the population in comparison to what would otherwise have prevailed. Such information on an individual level is practical is impossible in a large population as in our study.

We could not find an association between the radiation from the Chernobyl accident on thyroid cancer. Regarding the thyroid cancer the iodine status of the Swedish population is good in contrast to children in the former Soviet Union where a dramatic increase has been seen. This is probably making the Swedish population less sensitive in addition to that locally produced food plays a limited role in the areas with high fallout in Sweden. It is also possible that the radiation levels were too low in Sweden to cause an increased risk of thyroid cancer.

We were also unable to detect any clear increase in leukaemia during the follow-up in relation to the radiation from the Chernobyl accident. Similarly, not even in the most heavily polluted areas in the former Soviet Union any clear increase of leukaemia has been observed as yet, except a recent report from Ukraine. On the other hand, it has been suggested that the established association between ionising radiation and leukaemia is unique for the relatively high, but short exposure to radiation after the atomic bomb explosions and maybe not applicable in low dose studies.

The follow-up period is still rather short in our study and a longer study period is necessary for any more definitive conclusions about a causal relationship between the radioactive fallout in Sweden and the cancer incidence. Should we be observing some late stage promotion effect on ongoing cancer development in the population, there might even follow a decrease in the cancer incidence with an about normal cumulative incidence over a longer period of time. This remark, however, is a speculative conjecture to be addressed in future studies.

Reference

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Radiation Risk Assessment of Leukemia in Children of Belarus

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Abstracts. Results of an analysis of the incidence in the acute childhood leukemia in Belarus in 1980-2004 carried out on the basis of ecological model are discussed in the report. Published data of the Belarusian Republican Registry of Childhood Hemoblastoses and Hemopoiesis Depressions as well as the Belarusian Cancer Registry were used in the analysis. Only mixed childhood subgroup was considered without separating boys and girls. It was found that a short-time increase in the incidence of leukemia in children of Belarus (0 – 14 years at the time of diagnose) occurred in Belarus soon after the Chernobyl accident. The increase is statistically significant. After 1992 a decline in the childhood leukemia incidence began. As a result, the incidence in the childhood leukemia of Belarus after the period 1986-1992 became less than it was before the Chernobyl accident. 708 cases of acute leukemia were registered in Belarus in the period 1986-1992.

The number of expected leukemia in this period was assessed to be approximately 625 cases. These data give the standardized incidence ratio for the period 1986-1992 equal to 1.13 with 95% CI from 1.02 to 1.26. Radiation risks and attributive risk of leukemia incidence were assessed on the basis of an assumption that observed short-time increase in the childhood leukemia in Belarus had radiation origin. They are for the period 1986-1992: ERR = 7.8% per 1 mSv (95% confidential interval is from 1.0 to 15.4% per 1 mSv), EAR = 30.1 cases per 10^4 PYSv (95% confidential interval is from 3.9 to 59.2 cases per 10^4 PYSv), AR = 11.7% (95%CI is from 1.5 to 23%).

Introduction.

It is well known that hematopoietic tissues and organs are very sensitive to carcinogenic impact of ionizing radiation. This was established in epidemiological studies that have shown an increase of leukemia in different irradiated groups. It was found that infants and children have the highest radiation risks of leukemia [1-3]. This makes leukemia in infants and children a qualitative indicator of irradiation.

A number of epidemiological studies [4-15] were performed after the accident at the Chernobyl NPP in order to study the possible increase in the leukemia incidence in countries that were affected as a result of this accident. Results of these studies are quite controversial.

Petridou et al [4] found an elevated increase in leukemia in infants (from 0 to 11 months after birth) born in Greece in the period from 1 July 1986 to 31 December 1987. The incidence in leukemia in this cohort was by factor 2.6 (95% confidence interval, 1.4 to 5.1: p(2-tailed) ≈ 0.003: 12 cases in the 'exposed' and 31 cases in the control group) higher than in infants born in the periods 1/1/1980 to 31/12/1985 and 1/1/1988 to 31/12/1990 (control group). It was also found that the incidence in leukemia in infants born in contaminated areas in the period from 1 July 1986 to 31 December 1987 correlated with a level of a radioactive contamination. These results were established for areas with low contamination (less than 100 Bq/kg of soil), intermediate (999-1000 Bq/kg) and high contamination (> 1000 Bq/kg) with ^{137}Cs. According to our assessment, such contamination of soil corresponds with levels of the surface contamination in this isotop less than 5 kBq/m^2, 5 to 50 kBq/m^2 and higher than 50 kBq/m^2. Petridou et al [4] explained their findings as a result of an *in utero* irradiation.

The authors [4] established also some small and statistically insignificant increase in the leukemia incidence in children at the age 12-47 months at the time of diagnoses exposed in utero to Chernobyl radiation. The ratio of the incidence in leukemia of such children to the incidence of children born in the period 1/1/1980-31/12/1985 and 1/1/1980-31/12/1990 was equal to 1.1 (95% confidence interval, 0.8 to 1.5: p(2-tailed) ≈ 0.56: 43 cases in the 'exposed' and 266 cases in the control group).

Studies of the infant leukemia were performed also in Germany and Belarus [5-7] by using similar temporal cohorts as in the report [4]. Michaelis et al [5,6] compared incidence rates of infants born in the former FRG in areas with the ground contamination with the ^{137}Cs < 6 kBq/m^2, 6 –10 kBq/m^2, > 10 kBq/m^2 with the incidence of "unnexposed in utero" infants. They have found also an increase in the incidence in infant leukemia in West Germany, although smaller than in Greece (rate ratio: 1.48 with 95% CI: 1.02 to 2.15; 35 cases in the 'exposed' and 143 in the control group). However, no correlation between rate ratios and level of contamination was found in the German studies. Therefore authors [5,6] concluded that excess in the leukemia incidence occurred in infants in West Germany after the Chernobyl accident was not related to radiation.

An increase in the infant leukemia was observed after the accident in Belarus [7]. The rate ratio for entire Belarus including Gomel and Mogilev regions was found equal to 1.26 (95% CI: 0.76 to 2.10: 17 cases in the 'exposed' and 89 in the control group). In case of Gomel and Mogilev regions combined together the rate ratio was equal to 1.51 (95% CI: 0.63 to 3.61: 6 cases in the 'exposed' and 27 in the control group). These findings indicate the existence of qualitative correlation between the level of increase and level of contamination of Belarus. In this respect the Belarusian data agree well with data established by Petridou et al [4]. However, excess in the infant leukemia observed in 'exposed' cohorts of Gomel and Mogilev regions was lesser than in Greece despite the fact that average contamination of these regions is higher than the maximal contamination in Greece. This and the absence of statistical significance of rate ratios in case of the Gomel and Mogilev as well as entire Belarus was considered by authors [7] as an evidence that increase in the infant leukemia in Belarus had no link to *in utero* irradiation caused by the Chernobyl accident.

Controversial results were established also in epidemiological studies of the incidence in leukemia in children. Auvinen et al [8] compared incidence rates in leukemia in children in Finland observed in 1986-1988 and 1989-1992 with incidence rate registered in 1976-1985. According them a relative risk assessed for the period 1986-1988 was equal to 0.95 (95%CI from 0.80 to 1.35) and for 1989-1992 – 1.01 (95%CI from 0.87 to 1.17). An excess relative risk equal to approximately 7% per mSv (95%CI from –27% to 41%) have been estimated in this study for the period 1989-1992.

An analysis of childhood leukemia observed in 1986-1992 in areas with different surface contamination was undertaken in Sweden [9]. For all cases diagnosed after May 1986 in highly contaminated areas (> 10 kBq/m^2) compared with areas of low contamination (< 10 kBq/m^2) authors estimated the odds ratio equal to 0.9 (95%CI from 0.7 to 1.3). For acute lymphoblastic leukemia in children aged under 5 years at diagnoses the odds ratio in highly contaminated areas compared with areas of low contamination was 1.2 (95%CI from 0.8 to 1.9). Dose-response analysis undertaken by authors [9] showed no correlation between the degree of contamination and the incidence of childhood leukemia.

A slight increase in the incidence in childhood leukemia in Belarus was observed soon after the accident at the Chernobyl NPP in Belarus [10,11]. 655 cases of leukemia in children aged from 0 to 15 years were observed in Belarus in 1979-1985 and 708 in 1986-1992. The rate ratio assessed for these periods is 1.034 (90% CI from 0.946 to 1.131). The statistical power of the rate ratio was very low

(χ^2=0.383, p = 0.268). The observed increase in the childhood leukemia in Belarus after the Chernobyl accident, as can be seen from these data, was statistically not significant. No statistical significant change in the incidence in leukemia in the Belarusian children was found also in the report [12].

The importance of the incidence in the childhood leukemia that is a qualitative indicator of irradiation requires a careful analysis of different aspects of the childhood leukemia in Belarus before and after the accident. And this is the main aim of the present report.

Materials and Methods.

Data of the Belarusian Republican Registry of Childhood Hemoblastoses and Hemopoiesis Depressions (number of registered cases of leukemia) that were published previously [10-12, 15-17] were used in the report. The work on creation of the Registry has been begun in 1988. In course of it specialists of the Institute of Hematology and Transfusion of the Ministry of Health Care of the Republic of Belarus assessed under the scientific supervision of Prof. E.P.Ivanov all information on childhood hemoblastoses and hemopoieses. This information came to the Institute of Hematology and Transfusion from oncological dispensaries, clinics and polyclinics as well as from hematological consultative establishments. It includes the following data: the name and address of the patient, age, date, place of diagnosis, ICD number of diagnosis, and the diagnostic method (e.g. biopsy, autopsy, myelogram, immunohistochemical method used, etc.) [10-12]. These data are available for each oblast (region) of Belarus, the city Minsk (capital of Belarus) and for the entire country. There are 6 oblasts in Belarus: Brest, Gomel, Grodno, Minsk, Mogilev and Vitebsk.

Data of the Belarusian Cancer Registry for the period 2001-2004 [18-20] were also used in the present report. Numbers of children used in the analysis were determined on the basis of population census of the Republic of Belarus [21] and statistical handbooks [22-24]. The analysis was carried out for combined children's population without separate consideration of boys and girls. Using data on the leukemia incidence as well as other data time-averaged radiation risks of the incidence in childhood leukemia in Belarus were assessed.

The excess absolute risk was assessed on the basis of the following simplified expression:

$$EAR_j = \frac{O_j - E_j}{N^j_{PYSv}} \quad . \qquad (1)$$

Here EAR_j - excessive absolute risk in *jth* period of time, O_j and E_j - numbers of observed and expected leukemias in this period respectively, N^j_{PYSv} - number of person-years-sievert in the *jth* period.

The value of N^j_{PYSv} is determined by the expression:

$$N^j_{PYSv} = \sum_{i=1}^{n} H^{Coll}_{i,j} \quad . \qquad (2)$$

Here $H^{Coll}_{i,j}$ collective equivalent dose of the whole body irradiation accumulated from the beginning of irradiation to the end of the *ith* year in the *jth* period.

The excess relative risk was assessed by using the formula:

$$ERR_j = \frac{(O_j / E_j) - 1}{N^j_{PYSv} / N^j_{PY}}, \qquad (3)$$

where N_{PY}^{j} - number of person-years in the *jth* period of time.

The attributive risk , AR_j , was assessed on the basis of the expression:

$$AR_j = 100\% \cdot \frac{O_j - E_j}{O_j} \qquad (4)$$

Results and discussion.

Doses of irradiation

Table 1 presents cumulative doses of the whole body irradiation of the total Belarusian childhood population as a result of the Chernobyl accident. Data given in this table were taken from Table 3 of the report [25].

As can be seen from this table, collective and mean individual doses of the whole body irradiation to children of Belarus increased rapidly up to 1989 and then decreased slowly after achieving some maximal values. This temporal pattern of irradiation doses appears in case of children because the childhood subpopulation is an open system. Its composition is determined through two continuous flows. One flow is directed from outside to inside. This is the flow a newborn children. It adds irradiation doses to already accumulated doses. The second flow is directed from inside to outside. This is a flow of persons that achieved the age of 15 years. They leave the subpopulation of children carrying a fraction of accumulated irradiation doss to the subgroup of adolescents and adults.

Table 1. Cumulative collective and mean individual doses of the whole body irradiation of the childhood population of Belarus as a result of the Chernobyl accident.

Year	Collective	Individual	Year	Collective	Individual
	10^4 PSv	mSv		10^4 PSv	mSv
1986	0.25691	1.12204	1996	0.25159	1.17229
1987	0.3722	1.61069	1997	0.21916	1.0531
1988	0.42971	1.84569	1998	0.18428	0.91972
1989	0.45005	1.92296	1999	0.14706	0.7631
1990	0.43956	1.87717	2000	0.10972	0.58983
1991	0.42278	1.81315	2001	0.07712	0.43181
1992	0.38629	1.66962	2002	0.05883	0.3445
1993	0.34885	1.52541	2003	0.04834	0.29606
1994	0.31089	1.38177	2004	0.03834	0.24613
1995	0.28207	1.28037			

It was demonstrated in the report [25] that the main contribution to irradiation doses in Belarus gave irradiation in 1986-1989. After 1989 a significant decrease in irradiation doses occurred in Belarus. All those persons that were members of the children's subpopulation in 1986-1989 left this subgroup in 2004 because achieving of the age 15 years. And this caused significant decrease of irradiation doses of the children's subgroup.

Incidence in acute leukemia in children of Belarus

Figure 1 and Table 2 present time-averaged incidences in the acute childhood leukemia in different regions of Belarus. Three time periods are shown here. They are 1980-1985, 1986-1992 and 1993-2000. The time after the Chernobyl accident was divided in two periods: 1986-1992 and 1993-2000.

As can be seen from Fig.1 and Table 2, a short-time increase in the childhood leukemia occurred immediately after the Chernobyl accident in all regions of Belarus except the Mogilev oblast. In case of the Mogilev region a permanent decrease in the incidence in the childhood leukemia was observed in the period 1980-2000. The most plausible reason of this temporal pattern of the incidence in the childhood leukemia in case of the Mogilev region could be an incorrectness of the empirical data established for this region before the Chernobyl accident.

Data presented in Fig.1 and Table 2 demonstrate that time-averaged incidence rates in practically all regions of Belarus as well as in the entire Belarus in 1993-2000 were lower than in 1980-1985. This is an

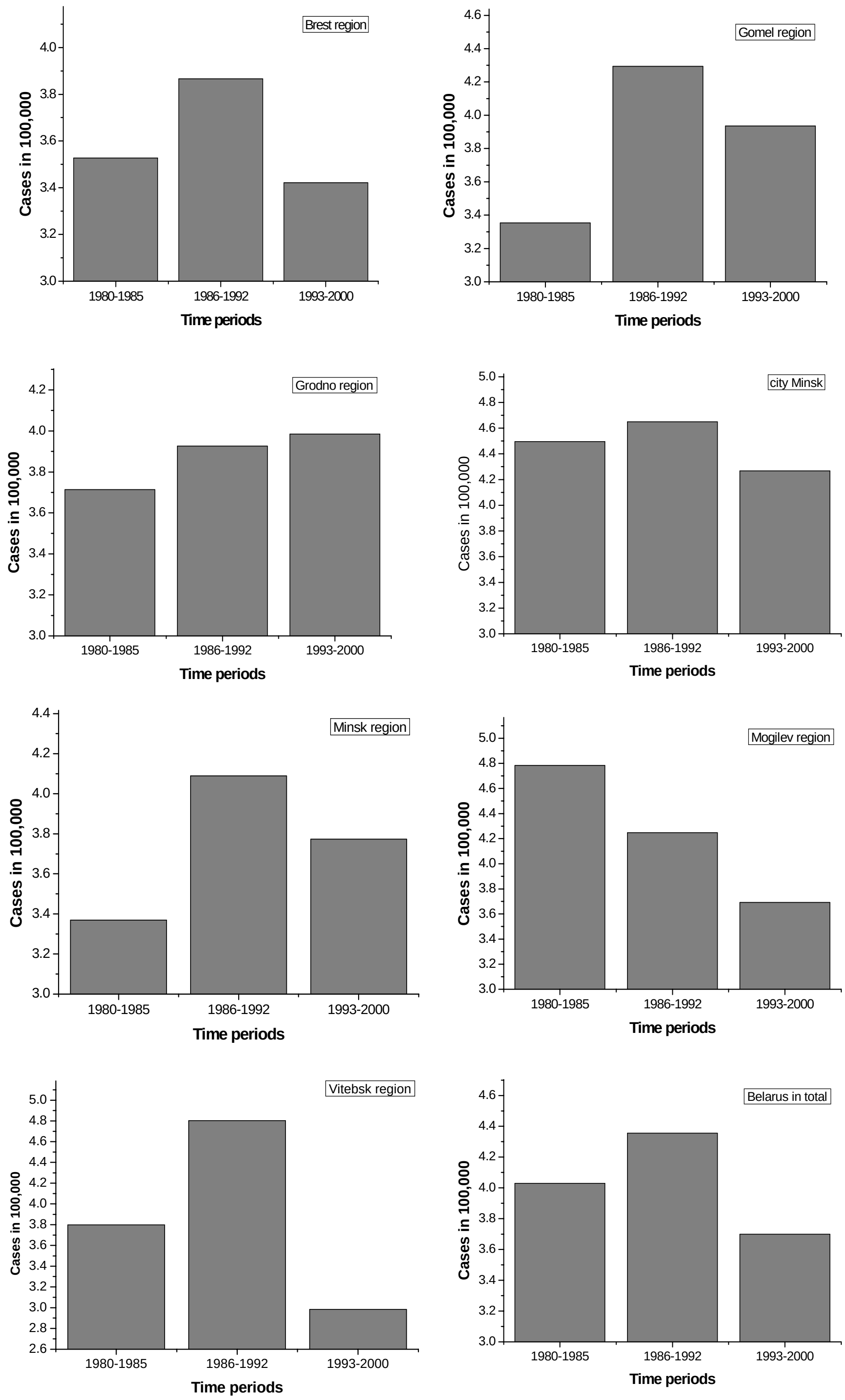

Fig. 1. Time-averaged incidences in the acute childhood leukemia in different regions of Belarus.

Table 2. Incidence in the acute childhood leukemia in regions of Belarus in 1980-1985, 1986-1992 and 1993-2000.

Region	Cases	Person·years	$IR \cdot 10^5$, a	$SE \cdot 10^5$, a
1980-1985				
Brest	80	2,268,213	3.527	0.394
Gomel	80	2,385,799	3.353	0.375
Grodno	59	1,588,899	3.713	0.483
City Minsk	90	2,002,278	4.495	0.474
Region Minsk	75	2,226,026	3.369	0.381
Mogilev	84	1,756,243	4.783	0.522
Vitebsk	70	1,843,033	3.798	0.454
Belarus	538	13,349,317	4.030	0.174
1986-1992				
Brest	108	2,793,433	3.866	0.372
Gomel	117	2,724,858	4.294	0.397
Grodno	71	1,808,251	3.926	0.466
City Minsk	122	2,623,805	4.650	0.421
Region Minsk	103	2,518,720	4.089	0.403
Mogilev	86	2,024,855	4.247	0.458
Vitebsk	101	2,103,497	4.802	0.478
Belarus	708	16,256,056	4.355	0.164
1993-2000				
Brest	92	2,718,244	3.385	0.353
Gomel	104	2,642,182	3.936	0.386
Grodno	77	1,932,447	3.985	0.454
City Minsk	113	2,647,839	4.268	0.401
Region Minsk	96	2,544,115	3.773	0.385
Mogilev	74	2,003,962	3.693	0.429
Vitebsk	64	2,145,307	2.983	0.373
Belarus	620	16,758,117	3.700	0.149

indication of a decreasing trend of spontaneous incidence in the childhood leukemia in Belarus

The slight decline in the leukemia incidence in Belarus began already before the accident at the Chernobyl NPP. This can be seen in Fig.2 that shows annual incidence rates in Belarus in the period 1980-1985 (left panel). The right panel of the Fig.2 displays annual incidence rates in the periods 1980-1985 and 1993-2004 combined together.

In case of data presented in the left panel of Fig. 2 only data of the Belarusian Republican Registry

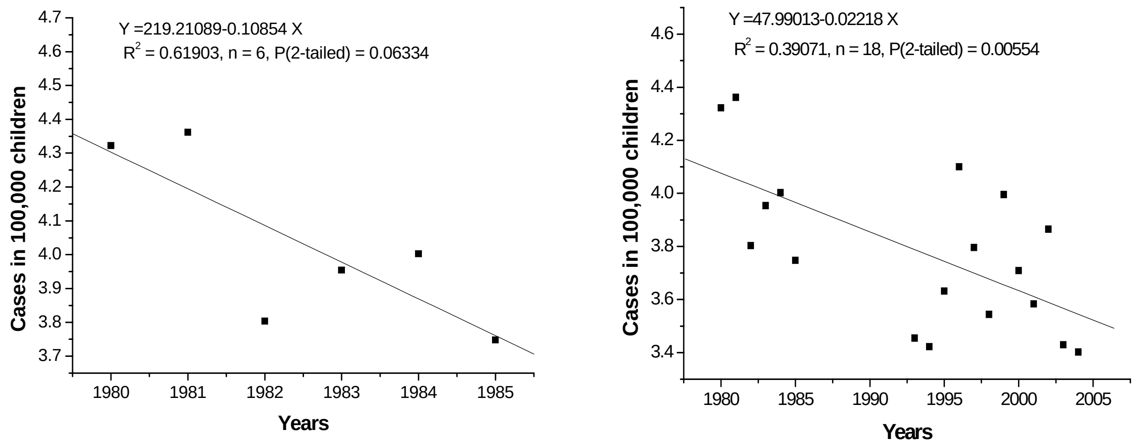

Fig.2. Incidence in the childhood leukemia in Belarus in 1980-1985 (left panel) and in 1980-1985, 1993 –1994 (right panel).

of Childhood Hemoblastoses and Hemopoiesis Depressions were used. The data presented in the right panel of this figure were constructed by using data of the Belarusian Republican Registry of Childhood Hemoblastoses and Hemopoiesis Depressions for the periods 1980-1985, 1993-2000 and data of the Belarusian Cancer Registry for the period 2001-2004 [18-20].

The decreasing trend in the childhood leukemia observed in Belarus before the Chernobyl accident indicates the necessity to analyze the increase of the childhood leukemia in Belarus after the Chernobyl accident on the basis of comparison of observed and expected incidences in this period of time. Three different simplified methods can be used for assessment of expected incidence rates in the period 1986-1992. At first, expected incidence rates in the period 1986-1992 can be determined as arithmetic means of empirical incidence rates estimated in periods 1980-1985 and 1993-2000. This method gives for the entire Belarus the value $3.865 \cdot 10^{-5}\ a^{-1}$ as the expected incidence rate for the period 1986-1992.

The second method of assessment is based on combining numbers of leukemia cases and person-years established in different periods of time. Assessment on the basis of Table 2 determines the total number of leukemias in registered in children of Belarus in periods 1980-1985 and 1993-2000 equal to 1,158 cases. The combined number of person-years in these periods is 30,107,434 person-years. Dividing of the first number by the second gives the value $3.846 \cdot 10^{-5}\ a^{-1}$. It differs only by 0.5% from the value assessed with the first method.

The third method in case of the entire Belarus is based on using the fitting expression shown in the right panel of Fig.2. It gives the value $3.877 \cdot 10^{-5}\ a^{-1}$ that is practically the same as values assessed by using two first methods. This means that any described methods can be used for estimation of expected time-averaged incidence rates of the childhood leukemia in the entire Belarus.

The analogous methods can be used also by estimation of expected incidence rates in the period 1986-1992 for separate regions of Belarus.

Table 3 presents standardized incidence ratios (SIRs) of the childhood leukemia in the period 1986-1992 estimated as ratios of observed incidence rates in the childhood leukemia in the period 1986-1992 to expected incidence rates in the same period 1986-1992 for separate regions of Belarus and for the entire country. The second method for estimation of the expected incidences was used by assessment of SIRs shown in this table.

As can be seen from Table 3, analysis on the basis of standardized incidence ratios demonstrates an increase in the incidence in the childhood leukemia in the period 1986-1992 in all regions of Belarus including the Mogilev region. The highest increase occurred in the Vitebsk region. It was statistically significant only in this region. The lowest increase occurred in the Mogilev and Grodno regions.

The use of standardized incidence ratios instead of rate rates demonstrates the existence of statistical significance of the increase in the incidence of the childhood leukemia in the entire Belarus.

Table 3. Standardized incidence ratios of the childhood leukemia in Belarus in 1986-1992.

Region	SIR	95%CI of SIR	χ^2 (1df)	P(1-tailed)
Brest	1.121	0.881 - 1.426	0.864	0.184
Gomel	1.173	0.931 - 1.479	1.831	0.091
Grodno	1.017	0.763 - 1.355	0.013	0.456
City Minsk	1.065	0.851 - 1.333	0.303	0.299
Region Minsk	1.141	0.893 - 1.457	1.116	0.146
Mogilev	1.011	0.777 - 1.314	0.0064	0.464
Vitebsk	1.429	1.104 - 1.850	7.420	0.00326
Belarus	1.133	1.017 - 1.261	5.168	0.0123

Radiation risks

It is clear, that any increase of the incidence in some cancer in population with the stabile age distribution (for example, in population of children) could be caused by two different reasons. At first, it can be a result of an improved screening of this cancer. At second, it can arise due to appearance of new carcinogen/carcinogens in the environment as well as a result of an increase in amounts of carcinogen/carcinogens that was/were in the environment before the increase in the incidence in this cancer. In the first case the incidence rate has to reach some increased value that remains constant later. In the second case, a decrease of the incidence will occur after some short-time increase in the incidence in cancer. Data given in the present report show a short-time increase in the incidence in the childhood leukemia in all regions of Belarus after the Chernobyl accident and the following decline. Such temporal pattern excludes the screening improvement as a main reason of observed increase in the incidence in the childhood leukemia in Belarus after the accident at the Chernobyl NPP. It is clear that appearance of new carcinogen/carcinogens or increasing of their amount is responsible for observed change in the leukemia incidence in Belarus after the Chernobyl accident.

It is remarkable that the observed short-time increase in the childhood leukemia manifested at the same time when a constant decrease in the chemical pollution occurred in Belarus [26,27]. It began in Belarus in seventies of the last century as a result of a transfer from the use of hard fuel to natural gas for electricity and heat production. This caused a significant improvement in the environment of Belarus. Starvation of industry and agriculture at the beginning of eighties contributed also very significantly to the improvement of the environment in Belarus [26,27]. As a result of these processes the discharge of different pollutants into the environment of Belarus decreased by factors 2-3 in the period 1985-2004 [26,27].

The decrease of antropogenic pollution caused by industry, agriculture etc occurred in Belarus simultaneously with an increase of irradiation as a result of the Chernobyl accident. All these facts indicate that radiation is the most probable factor that caused observed changes in the childhood leukemia in Belarus after the Chernobyl accident because this change can not result from the decrease in the amount of chemical pollutants.

There is only one finding that contradicts with the assumption that the increase in the childhood leukemia in Belarus after the accident at the Chernobyl NPP was caused by the impact of ionizing radiation. As can be seen from Table 3 standardized incidence ratio of the childhood leukemia in the Vitebsk region is the highest in Belarus. However this region was practically not affected by the Chernobyl accident [28]. Amount of radioactive substances deposited in this region is lower than in the Gomel region approximately by three orders in magnitude [29]. A question arises. If radiation were the origin of the observed increase in the childhood leukemia in Belarus after the Chernobyl accident why the standardized incidence ratio of the childhood leukemia in the clean Vitebsk region is than in the high-contaminated Gomel region?

There is a plausible answer on this important question. Probable the high value of the standardized incidence ratio of the incidence in the childhood leukemia in the clean Vitebsk region could be a result of the migration of inhabitants of high-contaminated territories of the Gomel and Mogilev regions to this region.

The migration began soon after the accident at the Chernobyl accident. In first 10 years after the Chernobyl accident 842.6 thousand of the Belarusian citizens or 8.4% of the total population changed the places of their living in borders of Belarus [30]. The internal migration (moving in borders of Belarus) was especially high in contaminated territories. According to information [31], approximately one sixth of inhabitants of the high-contaminated Slavhorod district (Mogilev oblast) left their contaminated settlements during three first years after the Chernobyl accident. The similar situation arose in other contaminated districts of this region. The process of migration was even more pronounced in contaminated areas of the Gomel oblast [30].

The total number of people that changed their place of residence in borders of Belarus in 1986-2000 is 1,500,000 or 15% of the averaged population that was approximately 10 Million persons in this period [30].

The internal migration in Belarus from contaminated regions of Belarus was occurring partly as a result of an implementation of the State Program of minimization of the Chernobyl consequences. On this way about 135,000 persons were resettled from contaminated to clean territories [32]. Approximately 200,000 persons migrated from contaminated areas of Belarus without any assistance of the state [33].

Simultaneously with internal migration an intensive external migration began in Belarus after the accident at the Chernobyl NPP. As a result of it only in 1990-2000 the country was left for other states of the world 675.1 thousand of the Belarusian citizens [30]. This is 6.75% of the total population of Belarus.

Significant fraction of people that emigrated from Belarus after the accident at the Chernobyl NPP lived on the territories affected by this accident. For example, approximately 130 thousand of persons of the Jewish nationality immigrated to Israel from contaminated areas of Belarus and the Ukraine [34]. About 50% persons from this number lived before the emigration in high-contaminated territories of Belarus.

It is evident that external and internal migration influences significantly the possible correlation between incidence rates in different disease and levels of a radioactive contamination caused by the Chernobyl accident. This influence had to be very significant in case of rare diseases such as the childhood leukemia. This indicates that more correct analysis of radiation risks of the childhood leukemia caused in Belarus as a result of the Chernobyl accident can be established only on the basis of data established for the total country.

Radiation risks of the childhood leukemia assessed on the basis of an assumption that increase in the incidence in the childhood leukemia observed in Belarus after the Chernobyl accident were assessed in the present report. Results of this assessment are presented in Table 4. They were estimated for two periods: 1986-1992 and 1986-2004. Data estimated by Auvinen et al [8] are shown also in Table 4 (fourth column).

Table 4. Radiation risk of the incidence in the childhood leukemia.

Parameters	This report		Auvinen et al [8]
	1986-1992	1986-2004	1989-1992
Person-years	16,256,056	39,698,347	
Observed cases	708	1,567	
Expected cases	625	1,484	
Observed-expected	83	83	
SIR	1.133	1.056	
95% of SIR	1.017 ~ 1.261	0.984 ~ 1.134	
$N_{PYSv}/10^4$ PYSv	2.758	4.833	
$EAR \cdot 10^4$ PYSv	30.1	17.2	
95% CI of EAR	3.9 ~ 59.2	-5.0 ~ 41.0	
h, mSv	1.694	1.151	0.47
ERR, %/mSv	7.8	4.9	7
95% CI of ERR in %/1mSv	1.0 ~ 15.4	-1.4 ~ 11.6	-27 ~ 41
AR,%	11.7	5.3	
95% CI of AR	1.5 ~ 23.0	-1.6 ~ 12.7	

For the assessment of data presented in Table 4, incidence rates in the childhood leukemia in the entire Belarus given in Table 2 were used. The expected incidence rate in the period 1986-1992 was then assessed by combining noncorrected numbers of leukemia cases established for periods 1980-1985 and 1993-2000 and respective person-years also presented in Table 2. Collective and mean individual doses of the whole body irradiation presented in Table 1 were used for assessment of radiation risks given in the second and third columns of Table 4.

As can be seen from Table 4 the relative excess risk of 7.8% per mSv (95%CI from 1.0% to 15.4% per mSv) was estimated for the period 1986-1992 for the entire Belarus on the basis of observed data. This value agrees very well with estimation of Auvinen et al [8] that found relative risk for Finnish children for the period 1989-1992 equal to 7% per mSv (95%CI from –27% to 41%).

Comparison with other studies

The very good agreement in radiation risks established in the present report and study [8] gives an additional evidence of a radiation origin of the short-time increase in the childhood leukemia manifested after the accident at the Chernobyl NPP in Belarus and Finland.

It is clear that a very good agreement in radiation risks found in this report and by Auvinen et al [8] could not be achieved simply by chance. Two sets of data are used for estimation of radiation risks. One set consists of data of medical statistical account. The second set consists of physical data such as contamination and irradiation levels. All these sets of data are quite different in case of children of Finland and children of Belarus. Therefore the existing agreement in radiation risks established in the present report and by Auvinen et al [8] gives an evidence that increase in the childhood leukemia manifested in Belarus and Finland is a result of irradiation caused by the Chernobyl NPP. The same conclusion can be drawn in respect of findings [4-5,9].

It is known that the rejection of link between radiation and an increase in the leukemia by infants [4-5,6] and children [9] observed after the Chernobyl accident is mostly based on results of analysis of the leukemia in infants and children of Belarus [7,10-12]. No statistical significance of the increase in leukemia incidence as well as no correlation between the incidence and correlation between contamination level was established in the reports [7,10-12]. However the reports [7,10-12] had significant methodical shortages. In case of reports [10,11] incidences in leukemia registered before the accident at the Chernobyl NPP were compared with data established in 1986-1992. The authors [10,12] could not find the statistical significance in the increase in leukemia in 1986-1992. However, data registered in Belarus after the period 1986-1992 demonstrate a decreasing trend of spontaneous childhood leukemia to the incidence before the Chernobyl accident.

An inappropriate method of analysis was used also in the report [12]. In this case the childhood leukemia in children of Belarus was analyzed by comparing annual incidences. Moreover boys and girls were analyzed separately. Such analysis was performed separately for different regions of Belarus. As a result, the children's population of Belarus was divided in the big number of subgroups. This splitting excluded any possibility to find the increase in the childhood leukemia in Belarus.

The indicated shortages and the influence of demographic factors are reasons for decreasing findings made in reports [7,10-12]. However, specialists in radiation protection concluded on the basis of these findings that there was no increase in infants and childhood leukemia in Belarus after the Chernobyl accident at whole [13,14]. As a result, they concluded the increase in infants and children leukemia observed in reports [4-6,9] had no any link to radiation.

Data established in the present report demonstrate that all these conclusions made in reports [13,14] are incorrect. The statistical significant short-time increase in the leukemia incidence occurred after the

Chernobyl accident in Belarus. The most probable reason of this increase is irradiation of Belarus as a result of the Chernobyl accident. The same conclusion can be made in respect of the increase in the leukemia incidence observed in some countries of Europe [4-6,9].

It is to notice here that ecological method was used in the present report as well as in reports [4-10-12,15-17] for analysis of the incidence in infants and children's leukemia. This method has significant limitations in interpreting of established results because both exposure and outcome are determined at the level group level. Therefore, ecological studies do not allow an assurance that the individuals who are exposed are actually those who develop the disease [35]. As a result of these limitations, ecological studies have significant problems by answering a very important question about possible threshold in inducing of the disease. For example, according to the assessment carried out in the report [36] doses of the whole body irradiation of the Belarusian population caused by the Chernobyl accident are in the range from some fractions of millisievert up to some hundreds of millisievert. It is impossible to determine on the basis of data estimated for the Belarusian children in the presented report if there is a threshold in case of the childhood leukemia.

Qualitative answer on the last question can give in case of the childhood leukemia ecological studies carried out in range of lower doses.

The highest dose of the whole body irradiation accumulated by of Finland in the first 2 years after the Chernobyl accident was 0.97 mSv [8]. It is known that irradiation dose of some small number of persons (critical group) in any irradiated group is by 3-5 times higher than the arithmetic mean dose. Assumption that radiation-induced leukemia in case of children of Finland developed in the critical group indicates, that ionizing radiation can induce radiation-induced leukemia at least at doses of the whole body irradiation in the range 3-5 mSv. This means that if the threshold exists in reality it can not be higher than 3-5 mSv in case of the childhood leukemia.

It was demonstrated in the previous section that radiation risk of the childhood leukemia in Belarus agrees very well with radiation risk established for children of Finland [8]. It is also quite close to radiation risk found for inhabitants of Hiroshima and Nagasaki irradiated at the age 0-9 years [37]. According the authors [37] excessive relative risk of leukemia incidence in persons irradiated at the age 0-9 years and followed up to the age 20 years is 44/Sv. This corresponds to a relative risk of 4.4% per mSv. This is a fully unexpected result. According the paradigm of radiation protection [38] radiation risk depends on doses and dose rates of irradiation. It is well known that doses and doses rates of the Belarusian population differ very significantly from doses and dose rates of survived inhabitants of Hiroshima and Nagasaki. The main contribution to the whole body doses of the Belarusian population, as can be seen from Table 1, gave irradiation in 1986-1989. In case of atomic bomb survivors the main fraction of dose was delivered within 1 minute [39]. Individual dose of the whole body irradiation of the Belarusian children was by 2 orders in magnitude lower than population dose of the atomic bomb survivors. The higher radiation risk of the incidence in leukemia in children of Belarus than in atomic bomb survivors despite of such immense difference in irradiation doses gives the clear evidence that using of the DRREF factor in case of chronic or protracted irradiation is not relevant at least in case of the childhood leukemia.

Conclusions

The analysis of the childhood leukemia in Belarus carried out for the period 1980-2004 indicates that the accident at the Chernobyl NPP caused manifestation of additional leikemias in the Belarusian children. Their number is about 83 cases in the period 1986-1992. The excessive relative risk of leukemia assessed for this period is 7,8% per 1 mSv. This value agrees very well with radiation risk found after the Chernobyl accident in Finland. Quite good agreement exists also of radiation risks estimated in this report with radiation risks established for atomic bomb survivors irradiated at the age 0-19 years. This is an unexpected result because of very significant difference in temporal patterns of irradiation of the Belarusian children and atomic bomb survivors. The dose rates of irradiation of the whole body in case of children of Belarus were approximately 10^{14} times lower than dose rates of atomic bomb survivors irradiation. The population doses of the whole body irradiation of the Belarusian children were lower by two orders in magnitude lower than in case of atomic bomb survivors. Despite these differences in doses and dose rates radiation risks of the leukemia incidence in children of Belarus are by some factors higher than in atomic bomb survivors. This indicates that the hypothesis about decrease of radiation risk with decrease of doses and dose rates is not relevant at least in case of the childhood leukemia.

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Trans-generational effects of radiation exposure from the Chernobyl Nuclear Plant Accident: A review of studies using mutation markers of repeat DNA sequences

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Introduction

The assessment of the possible radiation effects on the children who were conceived after the Chernobyl accident is needed in order to estimate the long-term health effects of the accident, including the effects on future generations. If germline cells were even exposed at the stage before conception, the health effect of children could be "trans-generational". Additionally, the health effects of children due to exposure to radiation might also be caused by exposure at successive stages after conception including the embryonic and fetal stages.

We already have definite evidence of the trans-generational effect of radiation from experimental animals. However, it has not yet been demonstrated in humans. The Radiation Effect Research Foundation (RERF) reported, "Extensive studies of the children of survivors of the atomic bombings in Hiroshima and Nagasaki have thus far yielded no statistically significant increases in genetic effects compared to control populations." They have done an on-going epidemiological study collecting mortality from all causes, and have performed molecular studies of DNA, as well as conducting a clinical health study investigating the frequency and prevalence of adult-onset life-style-related diseases.[1)] Under such circumstances, we have only the genetic risk assessment of radiation exposure, which was estimated from the data of spontaneous mutation rates in human Mendelian diseases and chronic multi-factorial diseases, and the data of the radiation-induced germline mutations of experimental mice.[2)] Studying the possible trans-generational effects induced by radiation exposure from the Chernobyl nuclear power plant accident is important in order to discuss the reassessment of the genetic risk of radiation. People who were exposed to the radiation from the Chernobyl accident form another large population, other than the atomic survivors of Hiroshima and Nagasaki where the radiation exposure was quite different.

This review focuses on the studies using mutation markers of repeat DNA sequences which is relevant to the radiation exposures that resulted from the Chernobyl accident.

Repeat DNA sequences as markers for detection of "trans-generational effects"

The choice of mutation markers is one of the critical issues in the studies of the trans-generational effects of mutagens including radiation. The markers should be sensitive and be able to effectively detect mutations, and the system should be capable of obtaining quantitative results of the dose-effect. Spontaneous mutation rates of protein-coding genes are at most in the order of 10^{-5}-10^{-6} per generation. Trying to detect trans-generational effects using markers of these coding genes requires very large number of samples. Therefore, it is not realistic to expect "significant results" using these markers in a population which is actually available for study.

There are considerable numbers of sites with repeat DNA sequences, multiple repeats of a certain sequence of bases (a repeat unit), in the genomes of various living things including human beings. The different numbers of repeat units at a site in the genomes of individuals of the same species may lead to polymorphic phenotypes. Most of the repeat sequences are in non-coding regions. These are sites, which can spontaneously mutate in high frequencies per generation. These sites can be used as markers to detect the genetic effects of mutagens in a limited-size population. In studies of the trans-generational effects of radiation, the results of research using markers of hypervariable minisatellites and microsatellites have been reported in human studies, as well as the results of experiments using markers of Expanded Simple Tandem Repeat (ESTR) in mice have also been reported.

Hypervariable minisatellites in humans are composed of varying numbers of GC-rich core repeats of 10 - 100 base pairs (bp). The core repeats within a stretch of minisatellite are related but are not identical. The total number of base pairs in a minisatellite is up to a few tens of thousands. There are more than ten thousand minisatellite loci in the human genome and most of them are situated close to telomeres. Some minisatellites exhibit spontaneous instability in germ cells with mutation frequencies as high as 10^{-1} - 10^{-2} per gamete, however such high mutation rates can not be seen in somatic cell lines. Recombination and gene conversion at minisatellite loci during meiosis result in complex changes in the loci, while recombination and slippage during mitosis lead to minisatellite instability of somatic cells. These different mechanisms for mutations are considered to be one of the reasons for such high instability found only in the germline.[3)]

Microsatellites in humans are composed of repeat units of less than 10 bp and the total length of a microsatellite is usually less than 100 bp. There are more than a hundred thousand microsatellites in the human genome and they are dispersed widely throughout the genome. The spontaneous mutation rate varies in each locus and is 10^{-2} - 10^{-4} per generation. It is considered that replication slippage leads to microsatellite mutations. A higher mutation rate was reported in paternal loci compared to maternal loci. Larger numbers of mitotic germline cell divisions in spermatogenesis than in oogenesis might be one possible reason for the difference in mutation rates between paternal and maternal germlines.[4)]

ESTRs of mice were at first cloned for their sequence homology to human minisatellites and they were called “minisatellites of mice” at first. However, their repeat units are only 5 - 6 bp and there is no variation of repeat units within a locus. Because of these structural differences between human and mouse minisatellites, these repeat sequences in mice were renamed ESTRs.[5)] Replication slippage is thought to cause the instability of ESTR although other mechanisms are possible.[3)]

Human experimental somatic cells showed a dose-dependent increase in mutation rates at minisatellite and microsatellite loci, when they were exposed to radiation.[6)] As for human germ cells, no increase was detected in the minisatellite mutation rate of sperm from volunteer patients who were given radiotherapy for seminoma.[7)] There is no similar research examining the radiation effects on the human microsatellite mutations of germline cells using samples from volunteer patients.

Induction of germline mutations of ESTRs in male mice by acute gamma irradiation was reported independently by two research groups.[8, 9)] The observed mutation frequency induced by irradiation was two orders of magnitude higher than the frequency which could be expected from the assumption that the DNA double strand break at the ESTR locus would cause the mutation. This suggests that ESTR loci might not be a direct target of radiation, but rather radiation might induce an indirect mechanism of some sort that would increase genetic instability in a cell.[3)] Further research is needed to clarify this mechanism. As for the most sensitive stage during spermatogenesis, different results were reported from these two research groups. Niwa’s group reported that the late spermatid stage of post-meiosis was most sensitive to radiation with regard to ESTR mutations.[9)] This result was compatible with the findings previously obtained from the experiments of the specific recessive loci in mice germline. On the contrary, Dubrova’s group reported that the pre-meiotic stages of spermatogenesis were sensitive.[10)]

Research on children living in contaminated areas of Chernobyl

In 1996, ten years after the Chernobyl accident, Dubrova et al. reported the results of studies on residents in the Chernobyl contaminated areas in Belarus, which showed that "the frequency of mutation was found to be twice as high in the exposed families as in the control group."[11)] This research drew the attention of the scientific community as it was the first "evidence" that radiation could increase germline mutations in human beings. In 1997, they published another report which included additional subjects and minisatellite probes to reinforce the results of the first report.[12)] However, these reports were criticized because they used samples of Caucasian families in the UK as the non-exposed control group which were of different ethnic origins than the Belarusian exposed families.[13)] Therefore, they conducted further research on the residents in the contaminated areas in Ukraine. In this study, they compared the children who were conceived before and after the accident, so that they could investigate the exposed subjects and unexposed controls from the same ethnic background. They analyzed the paternal and maternal mutation rates using eight single-locus hypervariable minisatellite probes and reported that "a statistically significant 1.6-fold increase in mutation rate was found in the germline of exposed fathers, whereas the maternal germline mutation rate in the exposed families was not elevated."[14)]

Dubrova et al. also investigated the populations around the Semipalatinsk nuclear test site in Kazakhstan, as well as exposed populations in rural villages along the Techa River, which were contaminated by radioactive releases from the Mayak plutonium separation combine. They used the same eight hypervariable minisatellite probes as mutation markers and again reported elevated minisatellite mutation rates in the exposed populations.[15, 16)]

However, the results reported from Dubrova's group were contrary to the findings of other groups which had also investigated human populations using minisatellite markers. Significant elevations of the minisatellite mutation rates were not detected in the reports of the study using sperm samples of volunteer patients whose testicles had been irradiated by radiotherapy for treatment of seminoma,[7)] in the research of families of atomic bomb survivors in Hiroshima and Nagasaki,[17-19)] or in the study of the families of Chernobyl clean-up workers who were called "liquidators".[20-22)] The reasons for this discrepancy are as yet unknown. Only the research group of Dubrova investigated the exposed residents in the contaminated areas. The residents in the contaminated areas were chronically exposed to low-dose-rates of radiation, while atomic bomb survivors and the Chernobyl liquidators were mainly exposed to high-dose-rates of radiation for certain limited periods. These differences in type of radiation exposure might be the reason for the discrepancy. In the case of the residents in the contaminated areas, exposure might not be limited to a specific stage of germline maturation, but could be a successive irradiation throughout the whole process of germline maturation and it could even include the stages after conception.

One of the backgrounds of these studies using minisatellite markers to detect the radiation effects on human germline was from previous studies using experimental mice. Mutation rates of ESTRs (these loci were formerly called "minisatellites of mice") of the experimental mice were significantly increased by acute gamma irradiation.[8, 9)] As mentioned above, because of the structural differences between human minisatellites and "minisatellites of mice", the latter were renamed ESTRs and different mechanisms are considered to cause mutations at these loci in mice.[5)] Radiation may possibly cause changes that increase the genetic instability in cells, which could lead to mutations of ESTRs in mice. Considering possible different mechanisms causing mutations, the experimental model of ESTR in mice cannot be directly applied to solve questions related to human minisatellite mutations. Further research for the mechanism of human minisatellite mutations is necessary before minisatellites will be used more widely as markers to detect and monitor the trans-generational effects of radiation in human populations.

Studies of the children of Chernobyl liquidators

As for the children of Chernobyl liquidators, results of studies using minisatellites[20-22] or microsatellites[22, 23] as mutation markers have been reported. There is no study as yet which has demonstrated “significant effects” with regard to germline mutations in liquidators.

The exposure period was much shorter in liquidators as compared to residents in contaminated areas; in most cases it was a period of up to several months. The radiation dose of individual liquidators varied widely depending on location and occupation. (However, the information on individual radiation dose was quite limited and usually external exposure alone was recorded.) In the studies of liquidators, only the paternal exposure was analyzed because the liquidators were largely men. Children conceived before the accident or residents in the non-contaminated areas of the same country were used as the non-exposed control groups.

Kiuru et al. studied the offspring of Estonian liquidators using the mutation markers of eight hypervariable minisatellite probes which Dubrova had also used in their study of residents. The minisatellite mutation rate was nonsignificantly increased among children born after the accident (Odds ratio: 1.33, 95% CI: 0.80-2.20). The rate was higher in the children born to fathers with recorded doses of 0.2 Sv or above (Odds ratio: 3.00, 95% CI: 0.97-9.30) relative to their siblings born before the accident, although this increase was not statistically significant.[21]

Livshits et al. reported that children of Chernobyl workers in Ukraine did not show elevated rates of mutations in minisatellite alleles. They used the five hypervariable minisatellites as mutation markers which had also been used by Dubrova. Their control group was made up of residents in non-contaminated areas in Ukraine. Their results showed as well that the mutation rate of the residents in the contaminated areas in Belarus (4.94%) was higher than the mutation rate of their controls (3.72%) that were residents of non-contaminated areas in Ukraine. This was reasonable as it suggested an elevated mutation rate in the residents in the contaminated areas as compared to those in non-contaminated areas; both groups were of similar ethnic background.[20]

The study using microsatellite mutations as markers to investigate the trans-generational effects of radiation in humans presents a more recent challenge than studies using minisatellites. The protocol for experiments using microsatellite markers is relatively simple: amplifying a target site including a microsatellite locus with a pair of primers, one of which is fluorescence-labeled, and analyzing the differences in length of PCR (Polymerase Chain Reaction) products using an automatic genetic analyzer. One of the advantages of this method is higher sensitivity which can detect even a difference in the length of a single base in microsatellite loci. However in the experiments using minisatellite markers, the sensitivity is less than this, with bands of different lengths of DNA fragments being analyzed in Southern Blotting.

However, as is mentioned above, the spontaneous mutation rate of microsatellite loci is one order less than that of minisatellite loci. Furitsu and Ryo et al. used as many as 72 microsatellite loci as mutation markers when they investigated a population of a limited number of liquidator families in Belarus. These 72 microsatellites loci were selected from the loci which had been reported in the literature as having higher spontaneous mutation rates. Analyzing the mutation of 40 Y-linked mincrosatellite loci, a higher mutation rate (2.9×10^{-3}) was detected in the families of liquidators in Belarus as compared to the mutation rate of the unexposed control group (2.1 x 10^{-3}), although the increase was not statistically significant.[23)]

There is not yet sufficient basic experimental data on the sensitivity to radiation with regard to microsatellite mutations in mammalian germlines. Further research on experimental mice and human populations with different radiation doses as well as various types of exposure is necessary.

Studies on living things other than human beings in Chernobyl-contaminated areas

There have been studies of mutations in DNA repeat sequences in barn swallows and wheat plants in the Chernobyl-contaminated areas. In the study of barn swallows, an increased germline mutation rate was observed at the two hypervariable microsatellite loci in populations breeding in Chernobyl- contaminated areas in Ukraine. European populations of barn swallows migrate across the Sahara desert, wintering in southern Africa. Ellegren et al. captured adult and nestling barn swallows (as "families") in Ukraine and Italy in 1991 and 1996. The mutation rate in the two microsatellite loci was 7.2% (number of meiosis investigated: 138) for the "families" in the contaminated areas. This rate was significantly higher than the mutation rates of control groups in the non-contaminated areas in Ukraine (3.8%, meiosis: 131) and Italy (2.0%, meiosis: 2,002).[24)]

In the study of wheat plants, two genetically identified populations derived from the same homogeneous parental line were compared. One population was grown in heavily contaminated plots of land near the Chernobyl nuclear power plant, the other was sown in a clean (<1 Ci/km^2) control area 30 km away with comparable agrochemical characteristics. They analyzed the 13 microsatellite loci in the offspring plants and estimated that the spontaneous mutation rate was 1.03 x 10^{-3} per locus (95% IC: 0.44 - 2.03 x 10^{-3}), whereas the mutation rate in the exposed group was 6.63 x 10^{-3} (95% IC: 4.28 - 9.70 x 10^{-3}).[25)] They also analyzed the complex pattern of microsatellite mutations in the germline of wheat and concluded that a simple model of replication slippage could not account for mutation events at these loci in wheat.[26)]

A study on the variation in the hypervariable portion of the mitochondrial control-region haplotypes in a population of the bank vole in northern Ukraine has been carried out, although it is not a study on the repeat sequences of nuclear DNA. Specimens of the bank vole exhibit the highest internal doses of radiocesium among small mammals inhabiting the most contaminated sites in Chernobyl. The rate of variation in the Chernobyl population was higher than in the control group living in less contaminated sites. This suggested that exposure to ionizing radiation in the contaminated environments increased the maternal mutation rate and has consequently increased mitochondrial DNA diversity.[27)] However, this increased diversity might be a function of asymmetric migration from a genetically diverse source population existing before the Chernobyl accident. The longitudinal genetic monitoring project is also on-going.[28)]

Plants and small animals usually alternate generations more rapidly than humans and they cannot intentionally avoid the environmental contamination. Therefore, it is very important to monitor the genetic changes of these living things in the contaminated areas to estimate the long-term consequences of the Chernobyl accident in the whole ecosystem.

Conclusion

In the studies of the children of Chernobyl victims so far, only Dubrova's study showed a significant increase in the mutation rate of repeat sequences of DNA, through research done on the residents in the contaminated areas using the markers of minisatellite loci. Other studies investigating the Chernobyl liquidators did not show any significant increase in the mutation rate even using the same hypervariable minisatellite probes as mutation markers and the same experimental method as Dubrova's group. This discrepancy might be due to the different types of exposure to radiation between residents and liquidators.

Further investigation is required to solve the question: to what extent the increase in mutations in repeat sequences would reflect in actual human health through its phenotype. Most of the repeat sequences in the human genome are in non-coding regions. However, some of them are known to cause diseases, or increase the severity of diseases, as they are in coding or modulator regions in DNA, or near them. The sensitivity to radiation in the repeat sequences, which relate to certain diseases, should be further examined and discussed concretely with respect to each site. If some radiation-induced mechanism, which leads to increased genetic instability in cells, would affect various regions in the genome other than in regions with repeat sequences, it could also influence the coding or modulator regions and induce a number of deleterious expressions of genes which might lead to the ill health of individuals.

Further research is needed on the mechanism and sensitivity for the induction of mutations through radiation exposure in DNA repeat sequences in the human germline, in each stage of germ cell maturation and also in the stages after conception.

As for the studies using microsatellite loci as mutation markers, the studies on barn swallows and wheat plants showed a significant increase in mutation rates, while studies on liquidators have so far failed to show a significant increase in mutation rates. The residents in the contaminated areas have not yet been investigated using the mutation markers of microsatellites. Basic data using microsatellite loci in experimental mice should be obtained. Further research using microsatellite markers with other human populations exposed to radiation in various ways should also be carried out.

In the studies which demonstrated significant increases of mutation rates in DNA repeat sequences, the observed mutation rate is much higher than the rate which could be expected from the assumption that the locus itself is the direct target of radiation and a double strand break at the locus can lead to mutation. This suggests that the loci might not have been directly targeted by radiation, but radiation might have induced some sort of mechanism to increase the genetic instability of a cell. The mechanisms, possibly including an epigenetic process, might be at work here and they could conceivably be common mechanisms for other biological effects of radiation, especially at low doses and through chronic exposure.

As mentioned above, there are still many unsolved problems regarding radiation effects on mutations of DNA repeat sequences. However, these results, including the significantly elevated mutation rate in mice ESTR, suggest that the genetic instability is actually increased by radiation to the germline. Therefore, it should not be ignored when we assess the risk of trans-generational effects of radiation. It is especially important in the genetic risk assessment of low dose and chronic exposure to radiation.

It is critical to carry out a long-range scientific monitoring of the trans-generational effect of the populations exposed to radiation from the Chernobyl accident. For that purpose, it is vital to establish an international research system in cooperation with the researchers in the affected countries.

Not only the environmental contamination by the Chernobyl accident but also other social and economic factors have affected the health of people in the Chernobyl areas. This complicated situation makes it more difficult to investigate the radiation health effects from the Chernobyl accident. It is not easy to study the radiation health effect separately from other risk factors. The exact radiation dose estimation is critical in assessing the health effects. However, estimating the exact individual radiation dose from both external and internal exposures can be problematic as it depends on multiple factors such as individuals' working conditions, life styles and so on. Therefore, analyzing health effects according to doses received by individuals who may be ill is not a simple process.

Many problems are still unsolved, even though more than 20 years have passed since the Chernobyl accident. Challenges in the scientific assessment of the various radiation effects of the accident, including trans-generational effects, remain with us. However, we should not just wait for the results of further research, which could provide us with scientific information about radiation, mutations and their relation to health effects in people, without taking any action right now. We must take action, if we seriously consider the wellbeing of future generations and remedies for the Chernobyl victims as well as the problem of nuclear energy in our society.

Table 1 and 2 are the summaries of reports so far on "Trans-generational effects" of human populations using mutation markers of minisatellites and microsatellite, respectively.

Table 1. Reports on the "Trans-generational effects" of human populations using mutation markers of minisatellites

A. Chernobyl Nuclear Power Plant Accident

(1) Dubrova et al. (1996) [11]

➢ Exposed group	● Residents in the heavily contaminated rural areas of the Mogilev province in Belarus: 79 families with children born between February and September 1994; both parents had resided continuously in the contaminated areas.
➢ Non-exposed control group	● Caucasian families in the UK: 105 families; sex was matched with the offspring in the exposed group.
➢ Estimated radiation dose	● The level of Cs137 contamination was 1-15Ci/km^2. Individual radiation dose for external and internal chronic exposure to Cs137 was estimated to be less than 5mSv/year.
➢ Minisatellite probes	● A multi-locus probe: 33.15(MS1, MS31), single-locus probes: MS32, CEB1.
➢ Main results	● The overall mutation rate was 1.97-fold as high in the exposed group as it was in the control group. ● Number of mutations / Total number of bands in offspring: exposed group [49/1615], control group[23/1491] ● Mutation rate was correlated with the level of Cs 137 surface contamination. ● Mutation spectrum (ratio between male and female germline mutations, gain or loss of repeat units, size distribution) was similar in both groups.
➢ Radiation Effects	● Positive

(2) Dubrova et al. (1997)[12]

➢ Exposed group	● Residents in the heavily contaminated rural areas of the Mogilev province in Belarus: 127 families with children born between February and September 1994 (male: 60, female: 67) ; both parents had resided continuously in the contaminated areas. (They added samples to the previous study reported in 1996.)
➢ Non-exposed control group	● Caucasian families in the UK: 120 families; sex ratio of children was matched with the offspring in the exposed group (male: 53, female: 57). (They added samples to the previous study reported in 1996.)

➢ Estimated radiation dose	● The mean dose over all families for parental external and internal chronic exposure to Cs137 was 27.6±3.3mSv.
➢ Minisatellite probes	● Multi-locus probes: 33.15, 33.6, single-locus probes: MS32, CEB1, B6.7, CEB15, CEB25, CEB36.
➢ Main results	● A 1.87-fold increase in the mutation rate was found in the exposed group. ● Number of mutations / Total number of bands in offspring: exposed group [136/6616], control group [56/5099] ● Mutation rate was correlated with the estimated radiation dose of the parents. ● Mutation spectrum (ratio between male and female germline mutations, gain or loss of repeat units, size distribution) was similar in both groups.
➢ Radiation effects	● Positive

(3) Dubrova et al.(2002)[14]

➢ Exposed group	● Ukrainian families inhabiting in the contaminated areas with 240 children conceived after the Chernobyl accident and born between 1987 and 1996; number of families [171+27], 27 families with children conceived before and after the accident.
➢ Non-exposed control group	● Ukrainian families inhabiting in the contaminated areas with 98 children conceived before the Chernobyl accident and born between 1976 and 1986; number of families [54+27], 27 families with children conceived before and after the accident. Ethnic background, maternal age, parental occupations and number of smokers of parents were similar for both exposed and control groups. The paternal age in the exposed group exceeded that for the control group.
➢ Estimated radiation dose	● The level of Cs137 contamination was >2Ci/km^2 and estimated dose from chromosome aberrations was 0.2-0.4Gy.
➢ Minisatellite probes	● Single-locus probes: B6.7, CEB1, CEB15, CEB25, CEB36, MS1, MS31, MS32.
➢ Main results	● A 1.56-fold increase in the paternal mutation rate was found in the exposed families. ● Number of mutations / Total number of bands in offspring: ∗ Paternal mutation: exposed group [112/178], control group [29/706] ∗ Maternal mutation: exposed group [25/1727], control group [10/701]
➢ Radiation effects	● Paternal: positive, maternal:negative

(4) Livshits et al. (2001)[20]

➢ Exposed group	● Liquidators families from Kiev in Ukraine; fathers had worked on the Chernobyl site during the period 1986-1987; 161 families with 183 children; 88 children were conceived while the fathers were working on the Chernobyl site or within 2 months after the fathers stopped working on the site and 95 children were conceived at least 4 months after the fathers had stopped working on the site.
➢ Non-exposed control group	● Families from southern Ukraine (non-contaminated areas); 163 families with 163 children.
➢ Estimated radiation dose	● 0.048 - 1.2 Sv. Data on individual dose estimate were provided for only 28% of liquidators.

➢ Minisatellite probes	● Single-locus probes: B6.7, CEB1, CEB15, CEB25, CEB36, CEB42, CEB72.
➢ Main results	● Only paternal mutations were analyzed and mutation rates per locus in the children of liquidators did not differ significantly from the control group. ● Number of mutations / Total number of bands in offspring (analyzing the result of paternal mutations using the seven single-locus probes): exposed group [53/1154], control group [51/1036]. ● Analyzing the result of mutation rates using the five single-locus probes, which were common to Dubrova's group: ＊ The mutation rate of the families in the contaminated areas of Belarus (4.94%, Dubrova's data) was 1.33-fold higher than the mutation rate of the families from non-contaminated areas in Ukraine (3.72%, Livshits's data). ＊ The mutation rate of the families from non-contaminated areas in Ukraine was 1.35-fold higher than the mutation rate of Caucasian families in the UK (2.75%, Dubrova's data).
➢ Radiation effects	● Negative

(5) Kiuru et al. (2003)[21]

➢ Exposed group	● Estonian liquidator families; father had been worked at Chernobyl over a median period of 3 months between 1986 and 1991; 147 families with 155 children born within 33 months after fathers were exposed at Chernobyl (post-Chernobyl children).
➢ Non-exposed control group	● The same 147 liquidator families with 148 children born before the Chernobyl accident (pre-Chernobyl children).
➢ Estimated dose of exposed group	● Mean radiation dose was 0.11±0.06 Sv with less than 1.4% of the cohort receiving more than 0.25 Sv.
➢ Minisatellite probes	● Single-locus probes: B6.7, CEB1, CEB15, CEB25, CEB36, MS1, MS31, MS32.
➢ Main results	● Mutation rate was higher in post-Chernobyl children than in pre-Chernobyl children but the elevation was not statistically significant (Odds ratio: 1.33, 95% CI: 0.80-2.20). ● Number of mutations / Total number of bands in offspring: exposed group [52/1238], control group [42/1182] ● Post-Chernobyl children of fathers with radiation dose of ≧0.2Sv had a threefold higher mutation rate (Odds ratio: 3.00, 95% CI: 0.97-9.30).
➢ Radiation effects	● Negative (There was some indication in the liquidator exposed group ≧0.2Sv.)

(6) Slebos et al. (2004)[22]

➢ Exposed group	● Liquidator families from Kiev and Chernigov in Ukraine; father had served in the cleanup operation of the Chernobyl accident between 1986 and 1990; 75 families with 75 children conceived after the start of the cleanup operation (within them, 39 families with 39 children did not have children before the start of the cleanup operation).
➢ Non-exposed control group	● 41 liquidators families from Kiev and Chernigov in Ukraine, from the same registry as the exposed group, with 41 children conceived before the start of the cleanup operation (within them, 5 families with 5 children did not have children after the start of the cleanup operation). Both "before" (control) and "after" (exposed) children in

	a family were conceived by the same mother.
➢ Estimated radiation dose	● Median accumulated dose was 152mSv.
➢ Minisatellite probes	● Multi-locus minisatellite probes: 33.5, 33.15
➢ Main results	● No statistically significant difference in mutation rates between exposed and control groups was observed. (Small sample size limited statistical power.) ● Number of mutations / Total number of bands in offspring: exposed group [9/82], control group [9/472]
➢ Radiation effects	● Negative (Small sample size limited statistical power.)

B. Nuclear tests

(7) Dubrova et al. (2002)[15]

➢ Exposed group	● Three-generations of families inhabiting the rural areas of the Beskaragai district of Kazakhstan around the Semipalatinsk nuclear test site: those in the first generation [P0] were born between 1920 and 1950, those in the second generation [F1] were born between 1951 and 1974 and those in the third generation [F2] were children of F1. 40 families with 135 of F1 and 97 of F2.
➢ Non-exposed control group	● Three-generations of families from the geographically similar non-contaminated rural area of Kazakhstan; matched with the exposed group by ethnicity, year of birth, parental age, occupation, whether or not they were smokers. 28 families with 83 of F1 and 65 of F2.
➢ Estimated radiation dose	● >1Sv
➢ Minisatellite probes	● Single-locus probes: B6.7, CEB1, CEB15, CEB25, CEB36, MS1, MS31, MS32.
➢ Main results	● A statistically significant 1.8-fold increase in mutation rate was found in the P0 generation and a less marked 1.5-fold increase was found in the F1 generation.
➢ Radiation effects	● Positive

C. Mayak plutonium separation combine

(8) Dubrova et al. (2006)[16]

➢ Exposed group	● Populations in rural villages along the Techa River, which were contaminated by radioactive releases from the Mayak plutonium separation combine; children conceived between 1950 and 1972; both parental exposure [53 families with 101 children], paternal exposure [10 families with 18 children] and maternal exposure [22 families with 40 children].
➢ Non-exposed control group	● 53 families of non-irradiated parents with 110 children: 49 families from the non-contaminated areas with children conceived between 1946 and 1977, and 4 families from the village along Techa River with all children born between 1950 and 1952 before the discharge; sex ratio, paternal age, parental occupation and number of smokers were matched with the exposed group, but maternal age in the control group was higher than that of the exposed group.
➢ Estimated radiation dose	● Mean paternal dose was l02±12mSv and mean maternal dose was 86±9mSv. Over 80% of the total parental dose was attributed to the internal exposure of the radionuclide.
➢ Minisatellite probes	● Single-locus probes: B6.7, CEB1, CEB15, CEB25, CEB36, MS1, MS31, MS32.

➢ Main results	● A statistically significant 1.67-fold increase in mutation rate was found in the paternal mutations, whereas maternal mutation rate was not elevated in the exposed families. ● Number of mutations / Total number of bands in offspring: * Paternal mutation: exposed group [42/861], control group [31/1044] * Maternal mutation: exposed group [6/980], control group [10/885]
➢ Radiation effects	● Paternal: positive, maternal: negative

D. Atomic bombings

(9) Kodaira, Satoh et al. (1995, 1996, 2004)[17,18,19]

➢ Exposed group	● Atomic bomb survivor families in Hiroshima and Nagasaki in which one or both parents received A-bomb radiation of > 0.01Sv (gonadal dose). Most of the children were born more than 10 years after the bombing. Within a total of 48 families with 61 children, 1 child had parents both of whom were exposed, 29 children had exposure only through the father and 31 children had exposure only through the mother.
➢ Non-exposed control group	● Atomic bomb survivor families in Hiroshima and Nagasaki in which one or both parents were exposed to less than 0.01Sv or the families which were not in Hiroshima or Nagasaki at the time of the bombing; 49 families with 58 children.
➢ Estimated radiation dose	● More than 75% of the exposed parents had an estimated dose of >1Sv (using a neutron RBE value of 10).
➢ Minisatellite probes	● Single-locus minisatellite probes: B6.7, CEB1, CEB15, CEB25, CEB36, MS1, MS31, MS32.
➢ Main results	● No evidence that the mutation clustered in individual offspring was found. ● Number of mutations / Total number of bands in offspring: * Paternal mutation: exposed group [11/240], control group [33/709] * Maternal mutation: exposed group [2/256], control group [6/694]
➢ Radiation effects	● Negative

E. Radiotherapy

(10) May, Tamaki et al. [7](2000)

➢ Exposed group	● Three seminoma patients aged 33-49 years donated semen samples after radiotherapy. The post-treatment samples represented sperm derived from cells irradiated at different stages of spermatogenesis, the sperms having been taken for several times on different days after irradiation.
➢ Non-exposed control group	● Sperm samples donated from the same three patients before having radiotherapy.
➢ Estimated radiation dose	● Total testicular X-ray doses were 0.75, 0.82 and 0.38 Gy for each patient.
➢ Minisatellite probes	● Single-locus minisatellite probes : B6.7, CEB1.
➢ Main results	● No significant difference in pre- and post-irradiation mutation rates was observed at any stages.
➢ Radiation effects	● Negative

Table 2. Reports on the "Trans-generational effects" of human populations using mutation markers of microsatellites

A. Chernobyl nuclear power plant accident

(1) Slebos et al. (2004)[22]

➢ Exposed group	● Liquidator families from Kiev and Chernigov in Ukraine; father had served in the cleanup operation of the Chernobyl accident between 1986 and 1990; 75 families with 75 children conceived after the start of the cleanup operation (within them, 39 families with 39 children did not have children before the start of the cleanup operation).
➢ Non-exposed control group	● 41 liquidator families from Kiev and Chernigov in Ukraine, from the same registry as the exposed group, with 41 children conceived before the start of the cleanup operation (within them, 5 families with 5 children, that did not have children after the start of the cleanup operation). Both "before" (control) and "after" (exposed) children in a family were conceived by the same mother.
➢ Estimated radiation dose	● Median accumulated dose was 152mSv.
➢ Microsatellite loci	● Autosomal loci: 4, X-linked locus: 1
➢ Main results	● More paternal mutations were seen in "after" children than in "before" children, although differences were minimal. ● Total number of mutations at the 5 microsatellite loci / Total number of microsatellite loci examined: exposed group [6/325], control group [2/174] ● D7S1482 demonstrated germline hypermutability.
➢ Radiation effects	● Negative (Small sample size limited statistical power.)

(2) Furitsu, Ryo et al. (2005)[23]

➢ Exposed group	● Belarusian liquidator families, in which either or both of the parents were involved in cleanup operations in the contaminated areas of Chernobyl between April 1986 and July 1987 during the periods from several weeks to several months; Total number of families examined was 64 with 73 children; among them, 61 children, whose fathers were exposed before conception, were analyzed.
➢ Non-exposed control group	● Belarusian families living in the non-contaminated areas in Belarus, in which none of the parents were involved in cleanup operations in the contaminated areas; sex ratio of the children were matched to the exposed group; 66 families with 69 children.
➢ Estimated radiation dose	● Very little information of the recorded individual radiation dose was available for this cohort. UNSCEAR (2000) reported that the mean effective dose was 39mSv for the liquidators in Belarus during 1986-1987 according to the national registry.
➢ Microsatellite loci	● Autosomal loci: 31, Y-linked loci: 40, X-linked locus: 1.
➢ Main results	● A higher mutation rate (2.9×10^{-3}) of Y-linked loci was detected in the families of liquidators as compared to that of the control group (2.1×10^{-3}), although the increase was not statistically significant. ● Number of mutations / Total number of microsatellite loci examined: * 40 Y-linked loci: exposed group [4/1392], control group [3/1458] * 31autosomal loci: exposed group [11/1852], control group [18/2108] * 1 X-linked locus: no mutations were detected in either exposed or control groups
➢ Radiation effects	● Negative

(3) Satoh et al. (1996)[18]

➢ Exposed group	● Atomic bomb survivor families in Hiroshima and Nagasaki in which one or both parents received A-bomb radiation of > 0.01Sv (gonadal dose). Most of the children were born more than 10 years after the bombing. Within the totally 50 families with 64 children, all children were exposed through either the mother or the father except one child where both parents had been exposed.
➢ Non-exposed control group	● Atomic bomb survivor families in Hiroshima and Nagasaki in which one or both parents were exposed to less than 0.01Sv or the families that were not in Hiroshima or Nagasaki at the time of the bombing; 50 families with 60 children.
➢ Estimated radiation dose	● Mean doses for gametes: maternal 1.7Sv, paternal 2.1Sv (using a neutron RBE value of 20).
➢ Microsatellite loci	● Autosomal loci: 3, X-linked loci: 2.
➢ Main results	● There was no significant difference in the mean mutation rate between the children of the exposed and control groups. ● Total number of mutations in the 5 microsatellite loci / Total number of microsatellite loci examined: exposed group [0/307], control group [4/809]
➢ Radiation effects	● Negative

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Cytogenetic Effect of Low Dose γ-Radiation in Plant Test-Systems: Non-Linear Dose-Effect Relationship

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Over several decades, modelling the effects of ionizing radiation on biological system has relied on the target principle [Timofeeff-Ressovsky et al., 1935], which assumes that cell damage or modification to genes appear as a direct consequence of the exposure of biological macromolecules to charged particles. It is assumed that there is no threshold for the induction of biological damage and that the effects observed are proportional to the energy absorbed. Following this principle, the average number of hits per target should increase linearly with dose, and the yield of mutations per unit of dose is assumed to be the same at both low and high doses. This principle has served as the scientific background for the linear no-threshold (LNT) concept that forms the basis for the radiological protection for the public and the environment [ICRP, 1990]. It follows from the LNT that there is an additional risk for human health from exposure to any radiation level, even below natural background.

Since the mid 50s, however, the scientific basis for the LNT concept has been challenged as experimental data have shown that, at low doses, there was a non-linear relationship in the dose response. Luchnik and Timofeeff-Ressovsky were the first who showed a non-linear response to a low dose exposure [Luchnik, 1957; Timofeeff-Ressovsky & Luchnik, 1960]. Since then, many data have been accumulated which contradict the LNT model at low doses and dose rates. However, the hit-effect paradigm has become so strong and indissoluble that it has persisted even under the growing pressure of scientific evidence for phenomena at low dose exposure that can not be successfully accounted for by the LNT concept.

In recent years, additional information on non-targeted effects of radiation has been accumulated following the first reports of an adaptive response in human lymphocytes [Olivieri et al., 1984] as well as bystander mutagenic effect of alpha-particles [Nagasawa & Little, 1992; Mothersill et al., 1995]. Other phenomena including genomic instability, low-dose hypersensitivity, and increased radiation resistance effects are also under study [Marples et al., 1997; Kadhim et al., 2004; Bonner, 2004].

The nonlinearity of the dose-effect relationship with low level exposures has been demonstrated in a number of studies where chromosome aberrations were considered as the endpoint of interest. For example, the number of radiation-induced dicentrics in human peripheral blood lymphocytes found in [Pohl-Ruling et al., 1983; Lloyd et al., 1988, 1992] did not exceed the control level at doses below 40 mGy, with some experimental points lying significantly below control values. Essential deviations of chromosome aberrations appearance from linearity in mammals were also shown at higher doses of 100-300 mGy [Luchnik & Sevankaev, 1976; Takahashi et al., 1982].

In other species, deviations of cytogenetic effect induced by low doses from linearity have also been reported. For example, the dose response for cytogenetic effects in Chinese hamster fibroblasts and *Vicia faba* germs at doses from 0 to 2.5 Gy was shown to be non linear with a plateau at low doses by [Zaichkina et al., 1992]. Frequency of chromosome aberrations in root meristem cells of *Pisum sativum* plantlets in the dose range of 0-10 Gy also showed non-linear responses with a plateau for doses up to 1 Gy [Zaka et al., 2002].

However the available information on dose-effect relationships at low doses for non-human species is scarce despite its importance. In their natural environment, some non-human species may be at a higher risk of impact than humans because of differences in ecological niches occupied [Geras'kin et. al., 2003]. Currently, radiation protection of the environment and maintenance of ecosystem sustainability is of a special concern and the development of a harmonized approach to human and biota protection has been recognized as a challenge for modern radiobiology and radioecology [Copplestone et al., 2004; Pentreath, 2002]. In this context, much more information on non-human species response to low level exposures is needed.

This paper summarizes findings of several studies on the cytogenetic effects induced by low level exposure to external γ-radiation in plant meristem cells.

Materials and Methods

Four of the experiments presented here were carried out on spring barley (*Hordeum vulgare* L., variety Zazerskiy 85) and one with *Tradescantia* (clone 02).

Barley is one of the most genetically well-studied crops and has been identified as an excellent organism for studies of induced chromosome aberrations [Constantin & Nilan, 1982]. Barley has 14 (2n) relatively large (6-8 μm) chromosomes which are easy to identify. In addition, a general procedure for root-tip aberration bio-assay is well-known, relatively quick and inexpensive to undertake. The following protocols were assigned for treatment and exposure of barley seeds and germs:

Protocol I. Dry seeds of *H. vulgare* L. were acutely irradiated with ^{60}Co γ-rays (in a "Gamma-Cell") at doses of 0.1, 0.5, 1, 5, 10, 25, 50, 100, 200, and 300 Gy. 24 h after exposure, the exposed seeds were placed in Petri dishes on distilled water-moistened filter paper for germination. Sections of main roots (approximately 5-10 mm long) were cut from 20-40 seedlings per dose point and fixed in acetic alcohol (1:3).

Protocol II. Seeds of *H. vulgare* L. were soaked for 24 h in distilled water at +4 ^{0}C in the darkness to synchronize cell division and provide evenness of swelling by beginning of germination [Konzak and Narayanan, 1977]. The seeds were removed from cold storage and maintained on moistened filter paper at 24 ^{0}C. After 12-16 h of germination, barley seedlings were irradiated with ^{137}Cs γ-rays at doses of 10, 50, 100, 150, 200, 300, 500, 750 and 1000 mGy at a dose rate of 0.5 Gy/h (Lutch Irradiator, Latenergo, Latvia). The germination continued until a root length of ≈ 10 mm was achieved and then 20-70 seedlings per dose point were fixed as above.

Protocol III. Seeds of *H. vulgare* L. were kept for 24 h in distilled water at +4 °C to synchronize cell division and exposed to ^{60}Co γ-rays at doses of 3, 5, 10, 50, 100, 150, 250, and 300 mGy at a dose rate of 60 mGy/h immediately after removing from cold storage, then allowed to germinate at +24°C in Petri dishes on filter paper wetted with distilled water. When the main root length reached about 10 mm, root tips of 20-80 seedlings per dose point were cut and fixed.

Protocol IV. Prior-exposure treatment of seeds was the same as in Protocol II. Doses of 5, 10, 50, 100, 150, 300, 500, 750, and 1000 mGy were delivered to seedlings 24 h after germination at +24°C at three dose rates of 120, 300 and 900 mGy/h with ^{60}Co γ-ray source ("Lutch Irradiator", Latenergo, Latvia). The germination continued until a root length of ≈ 10 mm was achieved. 15-50 seedlings per dose point were fixed as above.

Preconditioning of seeds in cold storage provides a simultaneous initiation of barley seeds' germination. So at the moment of irradiation, the cell population would be nearly homogeneous in terms of the cell cycle. Maximal frequency of scorable chromosome aberrations can then be registered in the first mitosis. However, it is not always possible to say precisely at what time cells come into mitosis as, in exposed cells, the cell cycle can be influenced not only by the treatment received (preconditioning, temperature, etc) but also by the type and severity of any impact (source of irradiation, dose rate, etc). From published data [Sandhu et al., 1994], as well as from our pilot studies, the first peak of mitotic activity in barley root tip cells was found at the moment when the main root reaches a length of approximately 10 mm, which was then taken as the point for samples to be fixed for cytogenetic analysis in the barley studies.

In all four studies with *H. vulgare* L., temporary squash slides for cytogenetic analysis were prepared from the root apical meristem of every seedling, coded and stained with aceto-orcein. In each slide, all ana-telophase cells (from 700 to 9800 cells at dose point in various studies) were scored to determine the fraction of cells with aberrations.

In the study with *Tradescantia* (2n=12), plants were grown under controlled conditions (t = 22 ± 1 °C; 18 hours per day of illumination at 11580 Lux; 44% air humidity). Irradiation was started at a moment when the first blossoming appeared in an inflorescence. At least 5 plants per dose point were exposed to γ-rays of ^{226}Ra during 72 hours with various dose rates so that the resultant doses amounted to 0.2, 1.1, 2.5, 9.1, 22.2, 54.9, 91.0, 267.4, and 422.4 mGy, as measured at the inflorescence position. Different dose rates were achieved by varying the distance of the plants from the source. Stamen hairs were analyzed from 4 up to 30 days of blossoming. Somatic mutations were registered according to [Ichikawa et al., 1978].

Results and discussion

<u>1. Aberrant cells in barley root tips after seeds exposure</u> (Protocol I)

Crops are an important component of food chains and have been extensively studied by the Russian Institute of Agricultural Radiology and Agroecology (RIARAE). Numerous radiobiological studies have been carried out in crops, including the study of the effect of ionizing radiation on reproduction potential of seeds (pre and post sowing) [Alexakhin & Korneyev, 1992]. With this historical background and the well-established techniques in RIARAE for seed irradiation, acute γ-exposure of seeds was used to study cytogenetic effects in crops induced by low and moderate doses to investigate the application of the LNT concept in non-human species [Geras'kin et al., 1993; 1995; 1997a].

Generally, the range of plants' radioresistance is higher than that of mammals, with dormant seeds being more radioresistant than during crop vegetation [Sarapultzev & Geras'kin, 1993]. The dose range in Protocol I was chosen to compare the plants radiosensitivity for different stages of ontogenesis. For example, it is known that, for Monocotyledons, radioresistance of dormant seeds is 4.8-5.6 times higher than that for vegetating plants [Sarapultzev & Geras'kin, 1993]. Thus, the doses from 0.1 to 300 Gy chosen for exposure of barley dry seeds could be considered as small (up to 5-10 Gy) and moderate dose values, regarding to high radioresistance of seeds.

Fig. 1 shows the frequency of aberrant cells (AC) observed in the root meristem of barley seedlings following exposure of the dormant seeds [Geras'kin et al., 1997a]. There is no significant difference from the control level following exposure to doses of 0.1 and 0.5 Gy. However at higher doses, the AC frequency is elevated compared with an unirradiated control, but the relationship shows no dependence on exposure applied in a range from 1 to 25 Gy, despite the 10 times increase in absorbed dose. Only at doses above 25 Gy is there an apparent linear increase in cytogenetic damage with increasing radiation dose.

Despite all the criticism directed towards the LNT concept, the fundamental principles regarding the interaction of radiation with DNA and other biological macromolecules is known to induce primary damage. Thus the effect of ionizing radiation at a molecular level is actually non-threshold as the energy of any charged particle is far above the binding energy in biological macromolecules. Consequently, a dose is specified as being low if a critical target receives not more than one radiation 'hit' [Kellerer, 1976]. Being aware of the critical target volume (i.e. size of cell or cell nucleus), it is possible to determine the

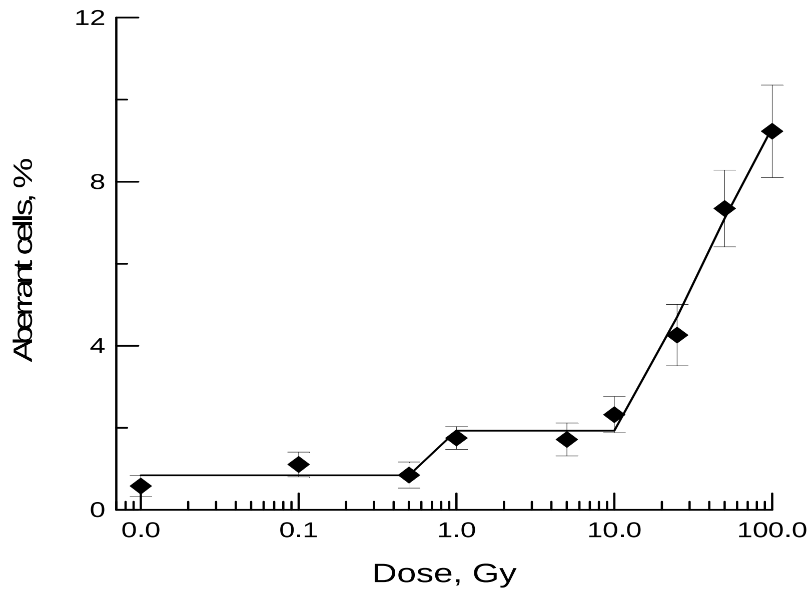

Figure 1. Frequency of aberrant cells (mean ± s.e.) in barley root meristem in dependence on dose absorbed by dormant seeds.

upper margin of low dose range based on the stochastic theory of radiation track distribution in a cell population [Spitkovskij et al., 1994b; Oudalova et al., 2002]. At doses from natural background up to this upper limit of the low dose region, the mean energy deposited in a cell's sensitive volume is a constant; with discordances from 'one-track' events being negligibly small. As the dose increases within this range, only the fraction of targets experiencing the radiation-absorption event increases linearly but not the energy absorbed in a single affected target volume [Bond et al., 1988]. Therefore, there seems to be no reason for an induction of response patterns different from background effect appearance, and an AC frequency should not differ significantly from the spontaneously observed level. This consideration underlies the first part of the dose-response curve in Fig. 1, i.e. between the control and 1 Gy, where there is no increase of the AC frequency over the control level.

At doses from 1 to 25 Gy, a 'plateau' in dose curve is observed. A dose-independence of cytogenetic effect in a low dose region of dose curves, 'plateau', has been reported in many studies, in particular, for human peripheral blood lymphocytes and melanoma cells, Chinese hamster fibroblasts, *Vicia faba* and *Pisum sativum* seedlings [Sevankaev, 1991; Shmakova et al., 2002; Zaichkina et al., 1992, Zaka et al., 2002]. To explain this deviation from linearity, most authors propose a hypothesis on radiation-induced repair system, which is triggered by a certain dose or certain level of biological damage [Luchnik & Sevankaev, 1976; Geras'kin, 1995a; Zaka et al., 2002]. In [Geras'kin, 1995b], induction of the mutagenic SOS-response, which is normally repressed, was suggested as providing restoration of cell survival but at the cost of an elevated frequency of genetic defects. At low doses, the contribution from radiation-induced effects compared with authentic spontaneous ones is rather small [Sarapultzev & Geras'kin, 1993; Pollycove & Feinendegen, 2001a] and so an increase in cytogenetic damage through misrepair appears important. The observation of the "plateau" in the dose dependency is a sign of the activation of repair mechanisms in response to the exposure received. These could be registered through alterations in other response patterns such as chromatin structure transformation or modifications in gene expression [Spitkovskij et al., 1994a]. Within the plateau range, the occurrence of scorable chromosome abnormalities reflects complex cellular responses that are triggered by the external insult (i.e. radiation exposure) but they do not depend on its value. As a result, an anomalous dose range is observed experimentally within which 2-10 fold changes in dose is not accompanied by any significant increase in chromosome aberration frequencies. As the dose increases further, the potential of the SOS-response systems to respond effectively decreases until it is overwhelmed and the dose-response curve then shows a continuous increase in cytogenetic effect with increasing dose.

2. Aberrant cells in root tips after germs exposure (Protocol II)

To reduce misinterpretation and uncertainty resulting from the influence of physiological processes which may occur during germination after seeds exposure to ionising radiation and prior to scoring of chromosome aberrations in seedlings, other experimental protocols were designed (Protocols II-IV) to expose germinated and not dormant seeds. Actively dividing cells of meristem tissues are the most radiosensitive parts of a plant. Previous work has demonstrated that the test-system of "AC frequency in the intercalary meristem of spring barley" is as sensitive to γ-radiation as the generally accepted test of "aberrations in lymphocytes of human peripheral blood" [Geras'kin et al., 1996].

The results of cytogenetic analysis in barley root meristem after irradiation of 12-16 h seedlings (Protocol II) at doses from 10 mGy to 1 Gy are presented in Fig. 2 [Geras'kin et al., 1999]. The relationship between AC frequency and dose is obviously non-linear. A significant difference in AC frequency from the control was found at doses > 50 mGy (p<5%, Kolmogoroff-Smirnov test [Sachs, 1976]). There are three parts to the dose curve which essentially describe differences in the dependences of the cytogenetic disturbance on dose. Thus, at doses from 500 mGy and higher, the AC percentage significantly differs from the control level (p<1%) and increases with increasing dose. However, within the dose range 50-750 mGy there are no significant differences in the AC occurrence, although the effect observed is higher than the spontaneous level of the AC frequency (p<5%). Hence, a 'plateau' in this study is revealed, and a non-linear relationship in dose-cytogenetic effect dependence is observed in barley root tip cells.

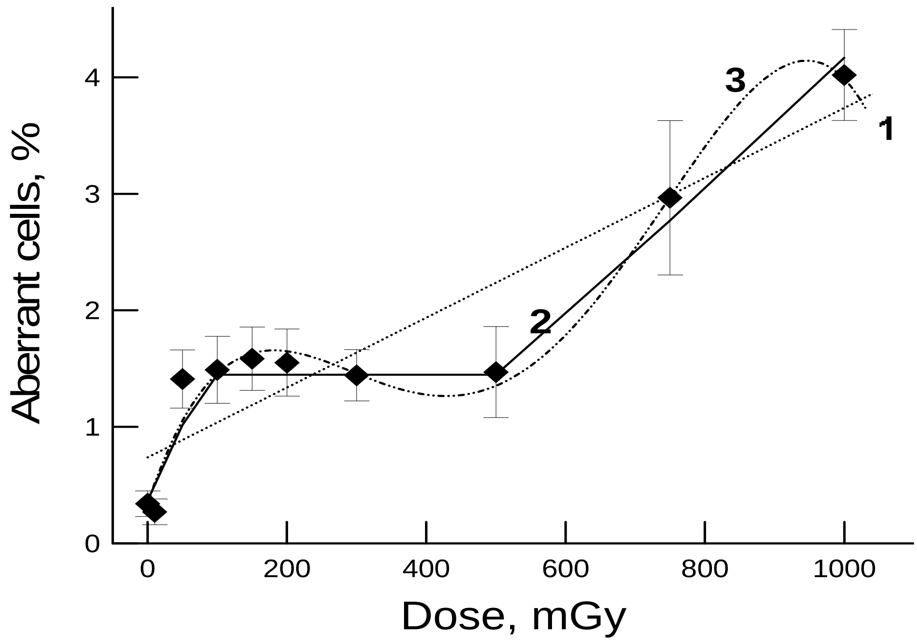

Figure 2. Frequency of aberrant cells (mean ± s.e.) in barley root meristem in dependence on dose absorbed by 12-16 h seedlings and approximation of the data with linear (1), piecewise linear (2) and 4th degree polynomial (3) models.

The use of the linear extrapolation from high doses into the low-dose region for an estimation of health risk and, correspondingly, in radiological protection, has been justified by a lack of reliable data, which are increasingly difficult to obtain at lower exposures because of large sample size needed [Upton, 2003; Brenner et al., 2003; Bonner, 2004; Tubiana, 1998]. At present, many authors have expressed the opinion that the validity of the LNT concept needs to be tested [Bonner, 2004; Tubiana, 1998, Mothersill & Seymour, 2004]. Under the increasing weight of experimental evidence which supports the non-linearity at low doses, there has been a shift in a perception of the LNT hypothesis from the indisputably correct dogma to one which is the most convenient, prudent and transparent operational tool in radioprotection and radiotherapy practise [Tubiana, 1998; Mothersill & Seymour, 2004]. In the interim, it is useful to test the application of the LNT concept and to continue to challenge its superiority from not only biological but also a mathematical viewpoint.

With this in mind, a comparison of goodness-of-fit of AC yields versus radiation dose using mathematical models of different types and complexities was performed on an example of the data obtained under Protocol II [Geras'kin et al., 1999; Oudalova et al., 2005]. A set of polynomial models ($y_m = \sum_{i=0}^{m} a_i \cdot x^i$) including linear function as a special case (m = 1), and a piecewise-linear (PL) model were used. The PL model pre-supposes a non-linearity of a dose dependency, which consists of several linear parts with different slopes, including a dose-independent plateau in a dose range [D_1, D_2], and has five free parameters.

For the polynomial models, values of free parameters were found from generalized linear regression [Draper & Smith, 1981]. In particular, an intercept and slope of the linear model ($y = a + b \cdot x$) are a = (0.74 ± 0.21) %, b = (3.00 ± 0.46) 10^{-3} %/mGy, correspondingly. Free parameters of the PL model were found using an iterative regression tool based on the method of coordinatewise descent [Vasiliev, 1988]. Important findings from the PL model verification are the lower and upper limits of the 'plateau' that are defined as D_1 = 83.4 mGy and D_2 = 513.7 mGy for the experimental data obtained in this study. Fitting the data on the AC frequency in barley root meristem with the linear and PL models is illustrated in Fig. 2.

The various models applied for the data approximation were followed by a quality review of these approximations with several different criteria, and the results are shown in Table 1. All six models are able to fit the data satisfactorily (F not less than 12.5, p<5%). However, the polynomial models of 2, 3, 4 degrees and the PL model show the lower values of residual sum of squires, SS_{res}, than the linear model, resulting in higher Fisher statistics, F, and multiple correlation coefficient, R^2 (Table 1). It is known that the predictive reliability of a model breaks down as the number of free parameters increases [Algorithms..., 1988]. To test the relative complexity of the models, the criteria of structural identification, T [Geras'kin & Sarapult'zev, 1993] was used. This method penalizes a model for the more additional free parameters it has; so that the lower T-value the more optimum the ratio between the complexity and goodness of data fitting the model has. From Table 1, the lowest value of the T-criteria is acquired by the polynomial model of 4th degree as well as PL model despite their 5 free parameters (np=5) and its correspondingly high complexity. This result means that the improved quality of approximation is reached not so much by making the model more complex, but due to its more adequate mathematical description (or, in other words, functional isomorphism) of the biological phenomenon.

To check the significance of the approximation improvement, a hypothesis was tested whether the linear model fits the experimental data significantly worse than other models, using the Hayek criterion, H, [Gofman, 1990]. From the calculated values of H (Table 1), the goodness's of experimental data fit by both the PL model and 4th degree polynom is significantly higher than by the linear model (H>$H_{0.95}$=1.96).

A common feature for two the best functions is a tendency to fit a 'plateau' in the cytogenetic disturbances occurrence (Fig. 2). The 4th-degree polynom is, however, consistent with the biological response observed only in the dose range studied, 0 – 1 Gy, while at higher doses this function drops to -∞ very fast, which illustrates an errancy of formalistic approach to data verification. On contrary, the good fit with the PL model is provided through conformity achieved between a biological phenomenon and its mathematical model. Consequently, this study shows that the PL model which assumes non-linearity of the dose-effect dependency, and implies the presence of a plateau, fits the cytogenetic disturbances occurrence in barley root meristem cells within the low dose range significantly better than any other among the tested models (and, in particular, better than the linear approach).

Table 1. Comparison of approximation quality of aberrant cells frequencies with different models. Data are obtained in dose range 0-1000 mGy (Protocol II) and 0-300 mGy (Protocol III)

Model	*np*	*0-1000 mGy*					*0-300 mGy*				
		SSR	***F***	***R^2, %***	***T***	***H***	***SSR***	***F***	***R^2, %***	***T***	***H***
1. Linear	2	1.80	41.7	83.9	0.45	-	0.41	24.4	77.7	0.12	-
2. Piecewise linear	5	0.30	180.2	97.3	0.30	3.55*	0.03	228.9	98.3	0.04	4.92**
3. Polynom (m= 2)	3	1.69	39.3	84.9	0.72	0.50	0.24	40.7	87.1	0.12	1.53
4. Polynomial (m= 3)	4	1.20	49.7	89.2	0.80	1.25	0.06	161.5	97.0	0.05	4.04**
5. Polynomial (m= 4)	5	**0.21**	**258.8**	**98.1**	**0.21**	4.35**	0.02	377.5	99.0	0.02	6.38**
6. Polynomial (m= 5)	6	2.70	12.5	75.8	4.06		0.01	459.5	99.4	0.02	7.09**
7. Piecewise linear II	3						0.11	91.3	93.8	0.06	2.84*

** – α<1%, * – α<5% - model fits the data significantly better than the linear model;

3. Aberrant cells in root tips after germs exposure (Protocol III)

The study of AC frequencies induced by low doses up to 300 mGy (Protocol III) was initiated to get more information on dose-cytogenetic effect relationship at doses below 50 mGy. The lack of such information became obvious at analysis and modeling of the previous experiment data at doses below 100 mGy, as there were only two experimental point below 83.4 mGy, the plateau lowest limit (Fig. 2).

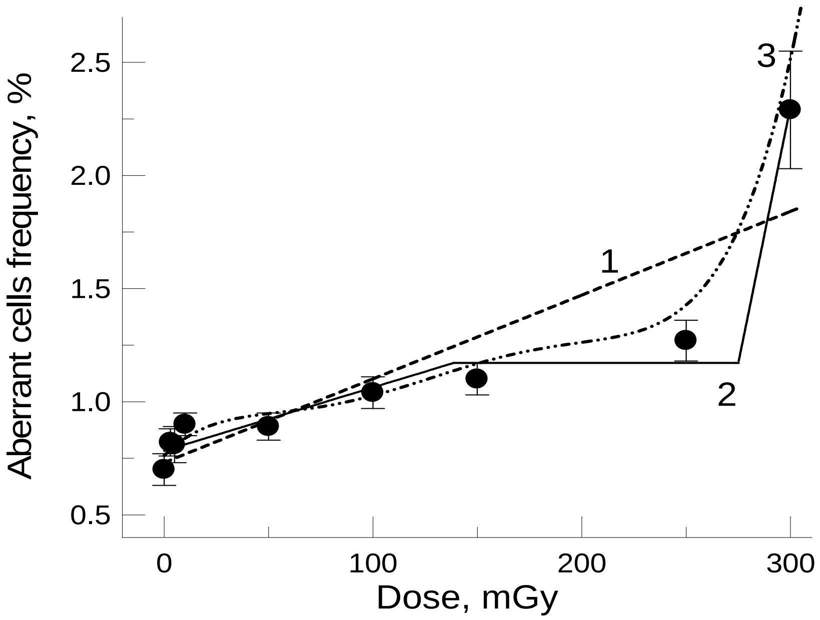

Figure 3. Frequency of aberrant cells (mean ± s.e.) in barley root meristem in dependence on dose absorbed by germs (Protocol III) and approximation of the data with linear (1), piecewise linear (2), and polynomial of 5th degree (3) models.

The common difficulty in assessing effects observed at low level exposures and making statistical inferences is related to the lack of a suitable quantity of available data to overcome uncertainties resulting from "experimental error" or "inter-species variation" when the induced effect itself has a small magnitude. In an attempt to provide a lower uncertainty of AC frequency estimates, exposure in this experiment was delivered to initiated barley germs immediately after their removal from cold storage, assuming that in this case a cell population would be found in the most synchronized state. Moreover, attempts were made to provide experimental volumes that were as large as reasonably possible. Thus, 2000-9800 ana-telophase cells were scored at different doses as opposite to 1300-2600 cells in the previous study.

Data from AC scoring are presented in Fig. 3. Significant increase of cytogenetic damage over the control level is found at a γ-rays exposure of > 100 mGy as follows from Student *t*-test, or > 50 mGy as follows from non-parametric Kolmogorov-Smirnov test ($p<5\%$), which is in a good accordance with the previous study. There are no significant changes in AC occurrence within the dose range from 3 to 100 mGy. AC frequencies at doses of 100, 150 and 250 mGy are significantly different to the control level, but do not differ from each other. The yield of cytogenetic damage at 300 mGy increases significantly over the values obtained at all other doses, even 250 mGy ($p<5\%$).

To test a validity of the LNT extrapolation, a goodness-of-fit of the data on the AC frequency approximation by different models was performed. A set of polynomial models, and several piecewise-linear models of different shape were used. The results are presented in Table 1. Piecewise linear model II assumes an absence of dose dependence below a threshold dose (D_0) and a linear dose-dependence at higher doses. All models were able to fit the data satisfactorily (F not less than 24, $p<0.1\%$). However the best models (Table 1) were the polynomial 5- (Fig. 3, curve 3) and 4-degree functions as well as the PL model that includes a 'plateau' (Fig. 3, curve 2). A common feature for these three best functions is an absence (for the PL model) or very slight dependence (for the polynomial models) of AC yield on dose at low doses, as can be seen from plotting the best-of-fit functions (Fig. 3). The linear function shows the worst characteristics of the data fitting (Table 1) obtained in this study.

4. Dose-cytogenetic effect relationship at different dose rates (Protocol IV)

It is well understood that the dose rate is of importance in assessing radiation-induced effects and the risks at low doses. Numerous studies have reported direct dose-rate effects, with an absence of dose-dependence and even an inverse dose-rate effect being found as well [Lyon et al., 1972; Sorensen et al., 2000; Min et al., 2003]. In the LNT concept, the risk of detrimental effects per unit absorbed dose is smaller for lower doses than at higher exposures, which is acknowledged by an application of the dose-rate effectiveness factor [Tubiana, 1998; Sorensen et al., 2000]. In territories contaminated after severe radiation accidents, both humans and the biota have been exposed to radiation at dose rates that varies through time and space, and the doses absorbed during the cellular and ontogenetic cycles of development are consequently a function of the dose rate. Therefore, an issue of varying dose rate is of high relevance in regard to radiological regulation and practice policy.

To study an effect of dose rate value on cytogenetic damage level, barley germs were exposed at three dose rates of 120, 300 and 900 mGy/h (Protocol IV) and ACs were scored in seedling root meristem [Oudalova et al., 2002]. Frequencies of ACs obtained in this study are presented in Fig. 4. Dose dependences at different dose rates keep the shape with a characteristic 'plateau' region of 10-300 mGy, and can be approximated with the PL model much better then with the linear one. There is a change in magnitude of the AC yield with a change of dose rate used. Remarkably, in the exposure range investigated, the induced cytogenetical disturbances appeared in a reverse dependence on dose rate, and the lower the dose rate the higher the AC frequency (Fig. 4). Significant increase over the control ($p<5\%$) was found from dose of 10, 100, and 500 mGy and above for dose rates of 120, 300 and 900 mGy/h, correspondingly.

Observations of a reversed dependency of mutation frequency [Lyon et al., 1972] and DNA damage [Min et al., 2003] on dose rate at low-level exposures are known. For example, more point mutations and chromosome aberrations per unit dose at low level radiation than at higher levels were found in [Shevchenko et al., 1972]. The most generalised explanation refers to an assumption of a diminished activation of repair at very low dose rates [Min et al., 2003]. In other words, the inducible repair system is probably activated by a certain threshold value of damage [Shevchenko et al., 1972; Calkins, 1973]. This means that, at low exposures, the accumulation of damage needs to reach a certain value or threshold before the repair mechanism is switched on. The lower the intensity of impact (i.e. dose rate) the more damage is required, which results in an inverse dependence of AC registered on dose rate in this exposure range.

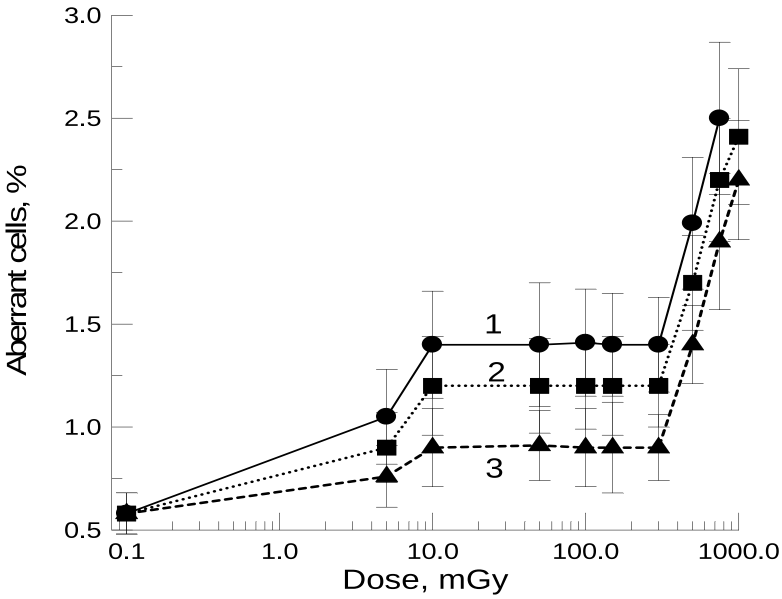

Figure 4. Frequency of aberrant cells (mean ± s.e.) in barley root meristem in dependence on dose absorbed by 24 h seedlings at dose rate of 120 mGy/h (1), 300 mGy/h (2), and 900 mGy/h (3).

An important finding of this study is that a non-linear shape of dose-effect dependence with plateau in low dose region is confirmed, and the independence of dose curve profile on dose rate in the studied exposure range is shown. An inverse dependence of chromosome aberration yield and dose rate is demonstrated for the first time in plant meristem cells, and requires further investigation. To obtain more information on the role of dose rate in cytogenetical damage induction patterns, a study identical to the work done under Protocol III has been launched but with several different dose rates.

5. Somatic mutations in *Tradescantia* stamen hair cells

To corroborate finding obtained with another plant system, *Tradescantia* (clone 02) was chosen as test-species in next experiment [Evseeva & Geras'kin, 2001]. *Tradescantia* has known as the best object for genetic and radiobiological studies [Sax, 1938; Ma et al., 1996] and been useful for detection of the genetic effects of both ionizing radiations and chemical mutagens at low exposure levels [Ichikawa, 1992]. The Tradescantia-Stamen-Hair-Mutation (Trad-SHM) bioassay uses the mitotic cells of stamen hairs for mutation induction in which the stamen hair cells mutate from dominant blue to pink constitutes a system unique in sensitivity; it can register doses of X-rays as low as several mGy [Sparrow et al., 1972].

Exposures in the study of radiation-induced somatic mutations in *Tradescantia* stamen hair cells [Evseeva & Geras'kin, 2001] were planned to provide detailed information at very low doses by choosing a dose interval between experimental points that was as small as possible. Experimental dependency of somatic mutation frequency on dose value presented in Fig. 5 demonstrates an obvious non-monotonous shape showing common features with dose dependencies obtained in barley studies (Fig. 1-4). Three dose ranges could be separated. At the exposure to doses of up to 9.1 mGy, the registered frequencies of

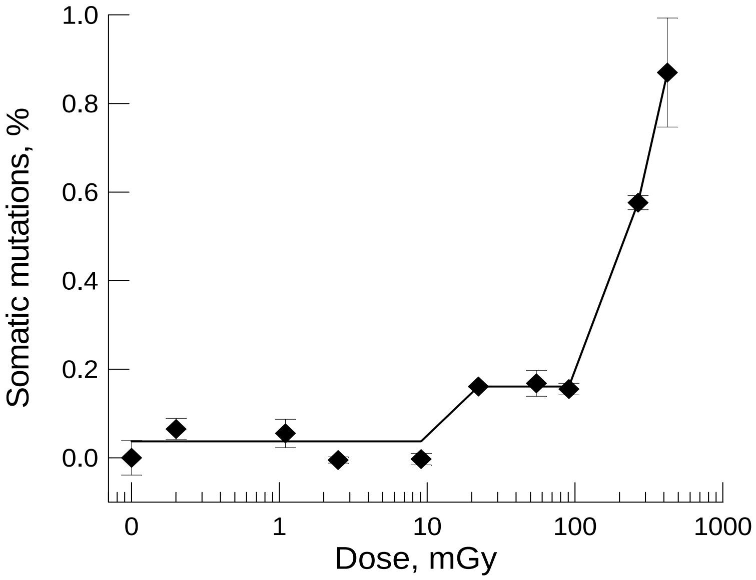

Figure 5. Frequency of somatic mutations (mean ± s.e.) in stamen hair cells from γ-ray-exposed *Tradescantia* plants

mutations do not differ from the level of spontaneous disturbances and are not significantly different from the control. In the second dose range, namely at doses of 22.2, 54.9 and 91.0 mGy, occurrence of somatic mutations is significantly higher than the control level and the values observed at the lower doses (up to 10 mGy) but does not significantly change within this dose range, which indicates a 'plateau'. When the dose increases over 100 mGy, a steady increase of the mutation frequency is observed; somatic mutation occurrence at doses of 267.4 and 422.4 mGy is significantly over the previous values at 0-9.1 mGy and 9.1-91.0 mGy.

Conclusion

In the present study, attempts were made to investigate the biological effect of ionising radiation at levels similar to those that may be observed in the environment. A correct assessment of risk of low doses for human health is impossible on a basis of current epidemiological data because of large uncertainties and experimental difficulties. There is a need to develop a more comprehensive understanding of the processes which govern cellular responses at low level exposures to ionising radiation. These processes are likely to have a lot in common, at least for eukaryotic organisms, because of uniformity in fundamental principles of genome organization and functioning. It is becoming increasingly clear that at low doses indirect and non-targeted effects play a crucial role in cell response that are, in some ways, similar to systematic stress [Mothersill & Seymour, 2004; Kadhim et al., 2004] and relevant to environmental toxins other than radiation. In this context, high sensitivity, low level of spontaneous mutagenesis, accessibility to large volumes of compatible experimental data, and acknowledgement in environmental genotoxins testing make those plant-based systems excellent models for studying low-dose effects.

The non-linearity and presence of plateaus in dose dependencies for cytogenetic disturbances have been reported in a number of works carried out with different species and test-systems. On the basis of these information and data obtained in several studies on cytogenetic effects in plant meristem, a concept of biological effect of low-level radiation on cell was suggested [Geras'kin, 1995b; Geras'kin et al., 1997b]. It postulates uniformity for different species relating to an essentially non-linear dose dependence shape, with only species-specific variations in critical doses at which slope modifications appear and that these critical doses depend on species radiosensitivity. The results of several studies presented in this review confirm the main postulates of this concept [Geras'kin, 1995b]. For example, the 'plateau' limits in dose curve observed by the Trad-SHM bioassay, 20-200 mGy (Fig. 5), are shifted down to smaller doses in comparison to 80-500 mGy for barley (Fig. 2), which is in a perfect accordance with a higher radiosensitivity of *Tradescantia* stamen hairs than that of barley cells. Furthermore, the concept [Geras'kin, 1995b] supposes an existence of one more dose-independent part that should not differ from the level of spontaneous cytogenetic variability. With the Trad-SHM bioassay, this theoretical prediction has, for the first time, received an empirical confirmation on vegetative object. Indeed, the high sensitivity and low level of spontaneous mutagenesis in *Tradescantia* made it possible to reveal such a dose range as low as 0.2 – 9.1 mGy (Fig. 5).

Ignoring the fact that the non-linear character of dose–response curves leads to a substantial underestimation of cancer risks, if high doses and linear dose–response curves are used for estimation of the hazard of low-level radiation, the following points can be made:

- Although many researchers believe that the estimation of cancer risks by the linear extrapolation of high-dose data to the range of low radiation doses may only give overestimated values [Tubiana, 1998], the data presented in this paper suggest that the LNT concept should not be used for estimating the risks of genetic defects induced by low-level radiation, since this concept has no sound biological underpinning and comes into contradiction with available experimental and epidemiological data [Gofman, 1990; Pollycove & Feinendegen, 2001b; Wei et al., 1990].
- The linear model is presumed to be advantageous as simple and prudent at modeling ambiguous biological effects at low doses, so its benefits follow from mathematical properties of the linear function, while the biological background of the LNT has been admitted as controversial. Findings of this work demonstrate, however, that it is not hard to call in question advantages of the LNT in fitting available experimental data from mathematics point of view, as well.
- New data obtained in these studies concern a perception of fundamental mechanisms governing cell response to low level exposures. These findings are of general biological interest, since response to low level exposures is one of the manifestations of basic laws determining and ensuring the living systems resistance and their adaptation potential under varying habitat conditions. An accumulation of information on cell responses to low level exposures and validating LNT hypothesis eligibility are relevant not only to an improvement of radiation safety standards but to the development of a general ideology for the public and environment protection. It should be acknowledged that more studies are needed for further validation of concepts for risk assessment at environmentally relevant levels.

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Social-economic Consequences of the Chornobyl Catastrophe

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1. Introduction

The largest in its scale and consequences man-caused catastrophe that took place on April 26 1986 on the # 4 Reactor at the Chornobyl Nuclear Power Plant in the former Ukrainian Soviet Socialist Republic became national tragedy, condemned millions of people to sufferings, and showed how unprotected was the state in the face of global disaster in peace-time.

The Chornobyl NPP disaster was responsible for serious economic losses within the former Soviet Union and beyond. The accident disrupted production as well as the normal activities of daily life in many areas of Ukraine, Belarus, and Russian Federation. In Ukraine, it led to a significant loss of electrical power production and a direct impact on the regional industrial economy. Further, it caused substantial damage to the agricultural economy and limited the use of the area's forests and waterways (use restrictions were imposed on 5,120 km^2 of farmland and 4,920 km^2 of forest). For the entire Ukraine population, the reduction in the Gross National Product and the loss of monies that could have been spent on improving health care and preventive medicine, and in other areas to promote general health and well-being was a significant blow.

In 1986, approximately 116,000 persons were evacuated from areas with radiation level higher than 5 mRem per hour**.** This evacuation required the construction of additional housing for the evacuees. Approximately 15,000 apartments; several living quarters with a total capacity exceeding 1,000 persons; 23,000 houses; and approximately 800 social and cultural institutions were constructed during 1986 and 1987. The city of Slavutych was built to house former Pripyat residents (Chornobyl NPP workers and their families). Other people from the contaminated areas were located in Kiev.

The measures implemented by the authorities immediately following the accident were designed primarily to protect the public from the effects of radiation and minimize the immediate threat to human life and health. The evacuation was accompanied by various measures. To provide social and economic assistance to the public and individual enterprises, machinery, equipment, livestock, and other materials were relocated to less contaminated areas.

Assistance to the affected regions in Russia, Ukraine, and Belarus was provided from centralized all-Union financial and technical resources in the Soviet Union. The assistance focused primarily on restoring daily living activities. These activities included employment; restoring production activities (e.g., restarting evacuated industrial facilities, finding alternate power sources); decontaminating houses and roadways in areas believed to be salvageable; as well as providing social assistance, environmentally uncontaminated products, and medical services to members of the public who continued to reside in contaminated areas.

2. Assessment of losses caused by the Chornobyl catastrophe for the USSR economy

The 116,000 people who were evacuated from their homes and those who voluntarily left (known as the victim population) were partially compensated for material losses related to the evacuation: lost personal property, crops in the ground, residences, etc. Industrial and agricultural enterprises (including collective farms) were compensated for lost financial, material, and technical resources.

In regions with radioactive contamination levels less than 555 kBq/m^2 (15 Ci/km^2) (intensive radiation monitoring zones), which were not subject to evacuation under the regulations, each resident was paid approximately 30 rubles ($33) per month to purchase "uncontaminated" food products imported from elsewhere. (At this time 1 kg of meat cost approximately 2 rubles and bread cost 20 kopecks.[1]) The use of local foodstocks (such as meat, milk, vegetables, and potatoes) was temporarily forbidden.

In 1990, the USSR Finance Ministry assessed the direct losses as a result of the Chornobyl NPP accident. The losses were determined by analyzing data provided by various ministries and agencies, as well as the industrial departments of the USSR Council of Ministers and the Councils of Ministers of the union republics. The USSR Finance Ministry found that the total direct loss (including expenditures from all funding sources) for 1986–1989 was approximately 9.2 billion rubles or about 12.6 billion US dollars [2]. As Ukraine's share of the all-Union budget was 30%, Ukrainian losses from the accident are in the same proportion.

In 1990, the USSR State Budget included 3.324 billion rubles for remediation of the Chornobyl NPP accident. Another 1 billion rubles was appropriated from the individual budgets of the Russian Federation and Ukrainian and Belorussian republics. The USSR State Budget for 1991 had included expenditures of 10.3 billion rubles for these purposes; however, because of the disintegration of the USSR, only a portion of the funding came from the all-Union budget. By the end of the year, remediation efforts were being funded by the state budgets of the three newly independent and most severely affected countries (Russian Federation, Ukraine, and Belarus), Gosstrakh (an insurance company), and voluntary contributions to the Chornobyl NPP Accident Remediation Fund. A total of 2.97 million rubles of foreign currency resources (including 2.2 million dollars in convertible currency) were also received and used.

3. Assessment of summarized economic losses of Belarus Republic

According to estimations of leading Scientific Research Institutes and specialists of various branches of national economy, the summarized social-economic detriment to Belarus Republic caused by the Chornobyl Catastrophe over the period from 1986 up to 2015 comes to 235 billion US dollars [3-5].

The sum includes losses connected with bad effects on population health, detriment to industry and social sphere, agriculture, construction complex, transportation and communication, municipal services; contamination of mineral and raw material, land, water, forest and other resources; also additional expenses connected with mitigation and minimization of the consequences of the accident and providing safe conditions for vital activities of population.

In the structure of total detriment during the years 1986 – 2015 the main part (81.6%) take costs, connected with industry functioning support and protective measures implementation, which come to 191.7 billion US dollars. The part of direct and indirect losses totals approximately 30.0 billion US dollars (12.6%). Lost profits are valued at 13.7 billion US dollars (5.8%). Direct losses include the cost of taking out of use of constituent part of national wealth of the republic: main and circulating production funds, objects of social infrastructure, living premises and natural resources.

To indirect losses are attributed those caused by influence of economic and social factors (living conditions and state of health of population) that caused disruption and cessation of production, slowing down labour productivity, rise of costs and aggravating provisions of other installations of state, co-operative and privet property, also losses inflicted by population migration from affected areas.

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[1] A kopeck is equal to one-hundredth of a ruble.

[2] This information was officially presented at an ECOSOC (UN Economic and Social Council) meeting by the USSR, Belarussian, and Ukrainian delegations (letter No. A/45/342 and E/1990/102 dated 06 July 1990 addressed to the UN Secretary General).

Constituents of lost profits evaluated in money are: reduction of output, works and services in the contaminated territories, cost of food turned useless due to radiological contamination, additional expenses in order to make up for production failed to be produced, cost of restoration of the lost quality of production, losses from canceled contracts, annulled projects, credits kept idle, penalty, fine and forfeit payments, etc.

Additional costs include expenses on mitigating of the consequences of the accident and securing of he normal functioning of different branches of national economy in radioactively polluted zones, and providing safe conditions for vital activities of people. They also include compensating of consequences of negative factors effects, cost of additional resources, used to compensate losses and lost profit, cost of decontamination measures and of radiological monitoring.

The cited above evaluation of losses is not final as cause and effect relationship, reflecting that the effects of radiological contamination of territories on various aspects of vital activities are rather complicated. Science still doesn’t have complete and final information on medico-biological, social and ecological consequences of the Chornobyl catastrophe.

Table 1. Sectoral structure of social-economic losses of Belarus Republic caused by Chornobyl NPP accident (billion of US dollars) [5]

Sectors of National Economy	years				
	1986-1990	1991-1995	1996-2000	2001-2015	1986-2015
Health of population	4.05	16.77	18.13	54.32	**93.27**
Agro-industrial complex	18.3	20.0	15.6	18.1	**72.0**
Forestry	0.58	0.68	0.70	2.15	**4.11**
Industry	0.06	0.13	0.11	0.33	**0.63**
Construction industry	0.15	1.25	0.32	0.96	**2.68**
Raw materials, mineral and water resources	2.00	0.12	0.15	0.40	**2.67**
Transportation and communication	0.93	1.20	0.36	0.90	**3.39**
Social sphere	2.84	5.45	2.96	6.45	**17.70**
Decontamination of the territories	0.04	4.19	22.48	10.12	**36.83**
Radio-ecological monitoring	0.05	0.21	0.19	1.27	**1.72**
Total	29.00	50.00	61.00	95.00	**235.00**

Belarus Republic still carries the burden of direct financial expenses for mitigation of the consequences of the Chornobyl catastrophe. For example, 200 million US dollars were spent on so-called “Chornobyl programs” from the state budget in 2004.

4. Assessment of summarized economic losses of Russian Federation

From 1986 through 1991 minimization of the consequences of the Chornobyl catastrophe in the Russian Federation was financed from the USSR budget. It should be mentioned that there is no data on the direct losses. It could be assumed that they were not as considerable as in Ukraine and Belarus, as there was no large-scale evacuation of population from the exclusion zone [6].

As for the period 1992 through 2000 when Russian Federation started to finance “Chornobyl” programs on her own, it was planned to allocate 247.7 billion rubles (on the value bases by the year 2000.) In fact during these years more than 46 billion rubles were finance from the Federal budget. Additional 36 billion rubles were paid as privileges and compensations, which gives us a total of more than 3 billion US dollars. Payments on “Chornobyl” programs from Russian Federation budget after the year 2000 are still kept in the same proportion.

5. Assessment of summarized economic losses of Ukraine

5.1. Direct losses. Direct expenses and indirect losses, including additional losses caused by prescheduled decommissioning of the ChNPP.

5.1.1. Assessment of direct losses

The city of Pripyat was completed in 1985 and had a population of 48,000 at the time of the accident. In 1986, the city contained three large enterprises under all-Union jurisdiction (Chornobyl NPP, the Jupiter plant, and an integrated residential construction plant); a vocational and technical school; a music school; a complex of hospital institutions; a recreation center; three libraries; and a movie theater.

When calculating losses caused by the consequences of the Chornobyl catastrophe, waste of infrastructure facilities located at the ChNPP construction site and in the territory of the exclusion zone, including the towns of Pripyat and Chornobyl are considered.

Losses caused by waste of material objects of national economy in the exclusion zone due to the Chornobyl NPP accident total to 1,010.6 million rubles (Table 2). [1]

Table 2. Losses from Ukraine Economic Facilities Removed from Service in the Exclusion Zone After the Accident.

Description of Physical Facility Lost as a Result of Chornobyl NPP Disaster	Year of Valuation as Fixed Asset or Inventory Item	Cost of Fixed Assets or Inventory Items	
		Rubles, thousands	Dollars, thousands
Facilities and expenses associated with stopping construction on ChNPP Phase III	1986[(a)]	99,028	136,120
ChNPP Unit 4	1964[(b)]	201,000	223,330
Chornobyl-2	1984[(c)]	97,700	137,027
Enterprises in telecommunications equipment industry (1)	1986	51,070	70,199
Enterprises in the metallurgical industry (1)	1986	44,700	61,443
Enterprises in the construction materials industry (1)	1986	7,750	10,653
Enterprises in the river transportation industry (2)	1986	21,050	28,935
Paved roads (353 km)	1986	60,550	83,230
Enterprises in the woodworking industry (1)	1986	4,720	6,488
Enterprises in the concentrated feed industry (1)	1986	4,550	6,254
Enterprises for primary processing of agricultural raw materials (1)	1986	4,900	6,735
Enterprises in the food industry (1)	1986	5,010	6,887
Enterprises engaged in the repair of tractors and agricultural machinery (1)	1986	760	1,045
Enterprises in the forestry industry (1)	1986	4,700	6,460
Collective farms (14)	1986	79,693	109,544
State farms (2)	1986	18,659	25,648
Joint enterprises (3)	1986	18,694	25,696
Water systems and facilities	1986	4,405	6,055
Sewer systems and facilities	1986	3,850	5,292
Electrical transmission and distribution	1986	315	433
Heating systems and facilities	1986	3,390	4,660
Housing space: - State-owned (402) - Privately owned (2,278) - Rural farmsteads (9,050)	1986	 209,750 7,101 28,200	 288,316 9,761 38,763
Vacation centers (10); hospital facilities (midwifery centers)	1986	29,104	40,005

Description of Physical Facility Lost as a Result of Chornobyl NPP Disaster	Year of Valuation as Fixed Asset or Inventory Item	Cost of Fixed Assets or Inventory Items	
		Rubles, thousands	Dollars, thousands
(44); Educational institutions in the vocational education system (3); general education schools (34); music schools (2); recreation centers (16); movie theaters (2); clubs (39)			
Total		1,010,649	1,338,979

(a)Exchange rate as of April 1986: $1 = 72.75 kopecks

(b)Exchange rate as of October 1984: $1 = 71.3 kopecks.

(c)Exchange rate as of 1964 $1 = 90 kopecks.

ChNPP = Chornobyl Nuclear Power Plant

In addition to the items in Table 2, the substantial loss of infrastructure facilities in the Exclusion Zone was accompanied by further losses of equipment, tools, and machinery that became contaminated with radionuclides during the accident remediation operations. These contaminated materials were disposed at the Buryakovka radioactive waste disposal site and at the Rozsokha Equipment Holding Facility 1 and 2. Items in the Buryakovka disposal site include 1,958 trucks, 14 fire trucks, and 19 bulldozers; the total estimated cost as of 1986 of the equipment in this disposal site was 17,566 thousand rubles or $24,146 thousand U.S. dollars (estimated cost as of 1986). This is from internal accounting data from Kompleks State Enterprise. Items in the Rozsokha holding facilities includes 30 helicopters and 11 residential buildings; the total estimated cost as of 1986 of the equipment in this holding facility is 16 million rubles or about $22 million U.S. dollars (estimated cost as of 1986).

The total loss -- loss of property and individual facilities of economic importance -- was 1,044 million rubles or $1,385 million U.S. dollars in the Exclusion Zone alone

Besides, other losses, caused by population evacuation and waste of fixed assets during the post-accident period, should also be considered. Those measures were taken after the radiation situation in the territory of the exclusion zone was specified in 1990's.

The cost of lost residential constructions and private property outside the Chornobyl exclusion zone equals to 0.2 billion rubles (as of the year 1984 prices.) The loss of fixed assets outside the exclusion zone equals approximately to 0.4 billion rubles (as of the year 1984 prices.)

Consequently, summarized direct losses of material objects and economic facilities outside the exclusion zone total 0.6 billion rubles, which is equal to 0.84 billion US dollars.

5.1.2. Assessment of Direct Costs

The cost of emergency measures was based on the general amount of financing of:

- works on direct mitigation of the consequences of the accident in the exclusion zone;
- social protection of the affected population and corresponding medical programmes,
- scientific research programmes;
- radiation monitoring of the environment;
- decontamination and RAW management

Summarized data on actual amount of financing is given in Table 3 [1]

Table 3.
Summarized data on actual amount of financing of mitigation of the consequences of the Chornobyl catastrophe and social protection of population for the period of 1986–1996 (1986 – 01.09.91 financed from the State budget of the USSR; from 01.09.91 – financed from the State budget of Ukraine) /in millions of US dollars/.

Line	Heading	1986 - 1991	1992	1993	1994	1995	1996	1997[(a)]
1.	Social protection of citizens, total	6606.55	197.33	196.51	478.07	383.97	545.65	636.93
2.	Special assistance	53.62	6.32	2.99	8.83	22.81	19.02	8.21
3.	Scientific research	57.76	3.23	4.45	4.99	5.92	7.04	10.54
4.	Radiation monitoring	63.79	1.99	1.64	2.28	3.15	4.44	5.4
5.	Environmental remediation	-	-	0.01	0.37	0.36	0.19	0.23
6.	Rehabilitation and disposal of radioactive waste	0.17	0.27	0.08	0.20	0.13	0.16	0.29
7.	Capital investment. Resettlement and creation of appropriate conditions for members of the public residing in contaminated areas	3173.62	276.07	197.78	205.28	167.44	194.10	89.87
8.	Work in Exclusion Zone	8923.75	19.70	25.84	46.45	44.95	52.08	56.1
9.	Other	228.97	17.72	15.88	25.91	41.94	43.36	37.0
	Total: Ukrainian portion*	19108.23 5732.47	510.81	436.01	755.72	638.30	835.19	844.6

*Assuming that in 1986-1991 the Ukrainian portion in the expenditures of all-Union budget was 30%, then the losses of Ukraine caused by the accident could be evaluated in the same proportion

Since 1998 from the State budget of Ukraine approximately in the same proportion to solve ‘Chornobyl’ problems expenditures were financed:

Year	Million US dollars
1998	584.72
1999	371.76
2000	332.64
2001	358.34
2002	376.00
2003	259.09
2004	450.11

It should be noted that since 2001 as the result of the pre-scheduled shut-down of the Chornobyl NPP Ukraine is put into additional expense to maintain safe condition of the shutdown reactor units of the Chornobyl NPP and to convert the object ‘Shelter’ into the ecologically safe system. Annual expenditure amounts approximately 50 million US dollars. Consequently, in the course of 4 years (up to 01.01.05) approximately 200 million US dollars were allocated for these purposes.

5.1.3 Analysis of Indirect Losses

Losses from inability to use contaminated arable lands, water and forest resources

The land contaminated by the Chornobyl NPP accident in Ukraine includes rich forests where mushrooms and berries were harvested and agricultural lands where thousands of metric tons of hay were harvested. The loss of the ability to use farmland, water resources, and forest resources because of contamination is currently estimated to be 8.6–10.9 billion rubles. This is more than 2% of the gross national income produced by Ukraine in 1986. These figures are for Ukraine alone from 1986–1991. All economic activity was suspended on land with contamination densities greater than 555 kBq/m^2 (15 Ci/km^2), and some activity was suspended on land with contamination densities between 185 kBq/m^2 and 555 kBq/m^2 (5 Ci/km^2 and 15 Ci/km^2). It will take several decades for the contamination on this land to decrease sufficiently to permit use.

Forestry industries also incurred significant losses. More than 5,000 km^2 of forest land was withdrawn from use. The direct losses due to loss of lumber were nearly 100 million rubles. The total loss incurred by forestry and related woodworking industries for the 1986–1991 time period was approximately 1.8–2.0 billion rubles (in 1984 prices).

Although only 0.6% of the pine stock in the former Soviet Union was located here, this area produced more than 50% of the total amount of resin collected in the former Soviet Union. Approximately 60,000 metric tons of coniferous sawdust per year, worth 15 million rubles, was collected here.

The loss to water resources and fisheries in the Dnepr and Black Sea watersheds because of radioactive contamination in bodies of water during the first few years following the accident was 2.3–3.1 billion rubles.

Thus, average evaluation of losses caused by inability to use contaminated arable lands, water and forest resources for the period of 6 years (1986 – 1991) gives us (8.6 + 10.9)/ 2 = 9.75 billion rubles. This indirect loss evaluated for a one year period gives us 9.75 / 6 = 1.625 billion rubles. In 30 years (to the year 2015) indirect losses in this field of activities will reach 1.625 × 30 = 48.75 billion rubles.

Loss of power production and its industrial impact

Because of the accident, electrical power was not produced using the Chornobyl NPP and goods and services were not produced because of the loss of power. These losses are especially important relative to the other losses resulting from the Chornobyl NPP accident. The amount of electrical power not generated because Unit 4 was not used for its entire design lifetime and because other Chornobyl NPP units were shut down in 1986 was 62 billion kWh. At a mean cost of 1.5 kopecks/kWh for Chornobyl NPP power, the direct loss was approximately 1 billion rubles. Economists estimate that each unit of electrical power cost supplied to other branches of industry increases national income by 20 units. Electrical power shortages have a substantial effect on production volume in areas such as machinery, light industry, food industry, and other processing industries. Thus, the total loss due to lack of electric power was approximately 20 billion rubles (in 1984 prices). < I think this estimate is acceptable in case there happened a large and long scale of electric shortage after the Chernobyl accident. I did not know such situation happened. Imanaka>

After the Chornobyl NPP accident, a moratorium was issued regarding bringing any new nuclear power plants on line at existing power plants. Because of this decision, the national economy failed to receive 6 million kW of installed capacity. Economists' estimates indicate that a mere 1-year delay in bringing 1 million kW of electrical power on line is capable of reducing the national income by 2 billion rubles. If the delay becomes long term, the cost of the moratorium could reach 48 billion rubles (in 1984 prices) within 4 years.

One might consider that the last mentioned arguments are not convincing. There are no known reports about long and deep shortage of electricity in Ukraine after the Chornobyl accident. But let us not forget, that at that time Ukraine was a part of the Soviet Union, which was a rather specific country. Beside it was large enough to mask underproduction of electricity in Ukraine by redistributing of its production and consumption over it's whole large territory, it was also closed country with the total control over information, especially that, which provided evidence of its weakening.

After disintegration of the Soviet Union the independent Ukraine in early and middle 90th of the 20th century faced problems of underproduction of electricity. The shortage in electricity production was so severe, that during autumn-winter periods the whole regions (including schools, hospitals and kindergartens), not only industrial enterprises, were being switched off electricity according to schedule or as a result of emergency cutout.

Of course it should be taken into account that the general economic and fuel crisis took place in Ukraine in middle 90th of the last century, but let us mention also that nuclear electrical power production was maybe the only stably operating branch of economy during this period. Since 1985 till 1993 electrical power production in Ukraine dropped down at 27% due to fuel shortage, but at the same time the share of NPP in produced electricity increased from 19.5 to 40% [7].

Thus, to summarize the indirect losses, the total irretrievable loss to Ukrainian economy from the Chornobyl NPP disaster is 116.75 billion rubles (in 1984 prices). The structure of the indirect losses is provided in Table 4.

Table 4. Structure of Ukrainian indirect losses due to Chornobyl NPP accident

Indirect Loss	Rubles in billions
Losses caused by inability to use arable lands, water and forestry resources	48.75
Cost of electricity not generated	20,0
Cost of moratorium against bringing new capacity on line at existing nuclear plants	48,0
Total:	116.75

As the exchange rate of the US dollar to the USSR ruble was approximately 71.3 kopecks, we can estimate the indirect losses as a result of the Chornobyl NPP accident to total 163.74 billion US dollars, or 3.4 times the Ukrainian gross domestic product for 1997. This is also as much as about 13 state budgets of Ukraine in 1997, or about 8 in 2005.< How many times larger than the state budget ?> It should be noted that indirect losses evaluation is given only on most affected branches of national economy.

5.2. Assessment of total economic losses of Ukraine

Direct losses (property and economic facilities) only in the exclusion zone in the territory of Ukraine totals 1044 million rubles or 1385 million US dollars.

Direct expenditures of Ukraine to mitigate the consequences of the Chornobyl catastrophe at the expense of different sources of financing during the period of 1986 – 1991 totaled approximately 6 billion US dollars. During the last 13 years, when Ukraine is independently financing costs of mitigation of the consequences of the accident, i.e. 1992 through 2004, expenditures reached 6.95 billion US dollars.

However, it is complicated to determine the scale of indirect losses, caused by inability to use contaminated agricultural lands, water and forest resources [2], decrease of power production, and sequentially decrease in output of goods and rendering services. The Ukrainian specialists estimations show that by the year 2015 summarized economic loss will come to 179 billion US dollars.

Consequently, summarized economic losses of Ukraine caused by Chornobyl catastrophe have the following scale and structure (**Table 5**)

Table 5. Structure of summarized Ukrainian economic losses till 2004

Item	Cost, million U.S. dollars
1. Direct losses of inventories and economic assets	
1.1 in the exclusion zone	1385.0
1.2 outside the exclusion zone	840.0
2. Direct costs of financing activities on mitigating of the consequences of the accident	
2.1 1986 – 1991 (Ukrainian share in the USSR budget expenditure)	5732.5
2.2 1992 – 2004 (Ukrainian expenditure after declaration of independence)	6953.3
3. Indirect losses according to Table 4 (for the 30 year period up to 2015)	163740
Total:	178650.8

These losses are not exhaustive, as they do not include all indirect Ukrainian economic losses but omit items such as:

– Loss of health and fitness for work (for the current and future generations)
– Future costs for reclamation of contaminated land and water bodies
– Future costs for decommissioning of the ChNPP, transform object ‘Shelter’ into ecologically safe system, disposal of radioactive waste from the Shelter.

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6. Conclusions and proposals

1. The accident brought out clearly that nuclear facilities safety expenses are considerably lower than those needed to mitigate the consequences of possible accidents – large-scale man-caused catastrophes do tremendous economic damage to countries that are located within the zone of their effect.

2. The Chornobyl catastrophe did enormous social-economic damage above all to three most affected countries: Ukraine, Belarus and Russian Federation.

As the result of direct losses of material and economic establishments and financial expenses on minimization of the consequences of the accident, the total sum of losses of Ukraine, Belarus and Russian Federation reached tens of billions of US dollars.

The Chornobyl accident is also characterised by considerable indirect losses, which **mean damnification caused by uderproduction in energetics, agriculture, forestry, fish industry, water facilities etc.I have changed this sentence< I can not understand the meaning. >**

3. Present estimations of indirect losses of Ukraine and Belarus are based on different methodological approaches and do not enable correct evaluation of health damage, demographic changes, future expenditure for rehabilitation of contaminated territories and facilities. In light of this development of universal approaches for estimation of indirect losses caused both by Chornobyl accident and other similar disasters are necessary.

4. Weight of expenditure to minimize consequences of the Chornobyl disaster will continue to be a heavy burden for the economy of three most affected countries for many years.

Considering that the extent of social-economic damage in Ukraine and Belarus is incommensurable with real economic resources of the countries, the assistance of the international community is essential.

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Do We Have Reliable Tool?
Considering the Efficiency of Chornobyl Legislation

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Among experts involved in the Chornobyl Disaster issues, one can often come across an opinion that the Chornobyl legislation is not part of the nuclear legislation. Therefore, it should be measured with a different yardstick. The nuclear legislation indeed does not identify Chornobyl-related laws as its part, rather referring to them for any Chornobyl Disaster issues like radiation protection measures, social security, and damage reimbursements. At the same time the makers of Chornobyl laws themselves admit that the issues of affected public social security and the Disaster's environmental after-effects are inseparable from radiation safety and radiological protection of population issues [1], having a far broader context than just that of Chornobyl.

On the year of Chornobyl Disaster 20th anniversary we find it reasonable to look back and see if we have learnt all the lessons taught by Chornobyl. It is an analysis of lessons-learned and recognition of mistakes that can significantly contribute to further progress in the area. The author of this text is convinced that common sense is a tool universal enough to study even such an extraordinary subject as the Chornobyl legislation, and attempts to analyze its efficiency will undoubtedly contribute if not to direct improvement of the situation, then at least to finding right ways to do so.

Efficiency of any means and measures is determined by their ability to achieve the set goal in the fixed time constraints and using determined resources. Of primary importance here is scientific validity of the goal itself, the relevant tasks to be carried out for goal attainment, ways to fulfil these tasks, and appropriate terms and resources allocated for it.

Today, 20 years after the Chornobyl Disaster, we have to admit that its consequences have not been overcome yet and that raises the issue of Chornobyl legislation as a means to overcome the Disaster consequences. Sad as it is, a major part of measures initiated in line with the Chornobyl legislation happen to have two common features – none of them were carried through and none of them satisfied hopes and expectations. The main reason for their sad fortune is usually claimed to be lack of funds allocated for their implementation. However, there is one more reason of no less importance, which is rarely realized and even less frequently mentioned – it is lack of scientific justification for these measures.

You will find no published information that by the time the Ukrainian SSR Verkhovna Rada (Parliament) approved Chornobyl laws in February 1991, there had existed detailed calculations of their implementation costs, however, back then it was clear this would be a serious challenge for Ukraine to tackle. The Ukrainian SSR Verkhovna Rada Decree № 797 dated February 28, 1991 "On the Order of Implementation of the Law of Ukrainian SSR "On Status and Social Protection of Population Suffered from Chornobyl Catastrophe" among other things charged the Ukrainian SSR Council of Ministers with following action items:

"- suggest to the USSR Cabinet of Ministers that 100% USSR Budget funding be allocated to cover the implementation of activities and measures mitigating the Chornobyl Accident consequences.

In case that proposal is rejected, reduce money deductions to the USSR budget assigned for financing activities and measures mitigating the Chornobyl Accident consequences."

One can find statistical information about the costs incurred by Ukraine to mitigate the Chornobyl Disaster consequences, and correlation data on planned and actual budget expense aimed at financing necessary measures stipulated by the Chornobyl legislation beginning with 1992 [2, 3]. But you will find no figures of funding needed to implement the complete set of measures according to the Chornobyl legislation, nor their correlation with the planned and/or actual cost to cover them earlier than 1996 [2, 4] (Table 1). Despite some discrepancies in the figures provided in the sources, analysis of the available data enables us to come to a number of conclusions.

First, financial requirements stipulated by the current legislation consistently tend to grow, going up as higher as 4.4 times in the 1996 through 2004 period. The tendency is caused by two reasons: inflation factors and increased cost of living on the one hand, and constant “improvement” of the Chornobyl legislation by amendments and addenda eventually resulting in multiplying amounts and numbers of benefits and compensations and widening the circle of people eligible for them on the other hand.

Second, there is a stable tendency towards increasing the gap between figures planned in the State Budget and those needed for the Chornobyl law implementation. In 1996 – 1998 planned financing reached 44–57% of the requirement, in 1999 – 2002 it went down to 21–29%, and 2003 – 2004 it made as little as 11% of the legally stipulated expenses. Paradoxical as it is, lawmakers keep increasing the expenses legally stipulated by the Chornobyl law, yet at the same time they limit budgeting of Chornobyl programmes by suspending articles and paragraphs of the laws at the point of adopting the State Budget Law of Ukraine, constantly limiting the scope of measures funded by the State Budget, a tendency obviously caused by awareness of the country’s inability to finance the whole set of programmes and also by doubts as for these benefits and compensations being valid.

The author of the text worked in 1991 – 2002 for the MinChornobyl (later the Ministry of Emergencies) Department for Public Radiation Protection and can with confidence state that during the whole period no attempts to substantiate or at least analyze the benefits and compensations stipulated by the Law of Ukraine “On Status and Social Protection of Population Suffered from Chornobyl Catastrophe” [5] were made in terms of radiological protection.

Third, all plans for financing Chornobyl programmes adopted by 1999 were never fulfilled, actual funding covering 55–87% of the plan, and it was in 2000 only that funding drew close to the planned.

The notion of a gap between the legally stipulated requirement and financial resources at the

Table 1. Status of financing the Chornobyl accident consequences elimination and affected population social security associated measures in 1996 – 2005. (million of UAH) [4].

Years	**Legally stipulated requirement**	**Budgeted for the given year**	**% to the require-ment**	**Actually financed**	**% of financed to budgeted**	**Outstanding debt at the beginning of the given year**
1996	3363.32	1794.56	53.4	1527.88	85.1	160.59
1997	5681.72	2513.00	44.2	1746.59	69.5	310.04
1998	4548.5	2606.00	57.3	1432.26	55.0	457.75
1999	6015.95	1746.80	29.0	1535.51	87.9	763.21
2000	7479.25	1812.89	24.2	1809.63	99.8	931.48
2001	8744.46	1843.99	21.08	1925.02	104.4	786.4
2002	9957.8	2144.5	21.5	2002.8	93.4	729.3*
2003	126567.4	1381.16	11.0	1381.16	100.0	760.3**
2004	14872.5	1710.97	11.5			685.4

* including 634.6 for social protection. ** including 596.4 for social protection.

State's disposal does not seem to be something new. It was already in the National Report dedicated to the Chornobyl Disaster 10th anniversary prepared by the Ministry of Chornobyl of Ukraine, where Clause 6.6. "Development of the Legal Basis for Population Protection from the Consequences of Chornobyl Catastrophe" stated a disparity between the legislation and economical potential of the country, being a source of constant social tension [3].

Under the given conditions Ukrainian authorities were naturally forced to seek help on behalf of the international community. The issue of international assistance for Ukraine to remedy the Chornobyl Disaster consequences could make up the subject for a separate study, while we will limit ourselves to stating that Ukraine has received substantial assistance, yet its volumes tend to shrink in the recent years, making sense to revisit the validity of assistance requests and that of Chornobyl legislation itself. The situation gets clearer if viewed in retrospect.

One of the key moments that determined further ways of planning and implementing the measures of public protection against the Chornobyl Disaster consequences, was "Concept of Popular Residence on Territories of Ukrainian SSR with Increased Levels of Radioactive Contamination as a Result of Chornobyl Accident" (hereafter referred to as the Concept) adopted by the Ukrainian SSR Verkhovna Rada in 1991 [6]. The Concept holds the main population radiation protection principle to be step-by-step resettlement of population from the affected areas to the radioecologically clean regions against a temporary criterion of soil radionuclide (caesium, strontium, plutonium) contamination density.

The main argument substantiating this principle referred to unavailability of comprehensive data as to the radiological situation on the Ukrainian territory and additional public exposure doses received since the ChNPP Accident and those that could yet be received throughout the residence on contaminated territories.

This principle and radioactive contamination density criterion served the basis for contaminated area zoning stipulated by the laws "On the Legal Regime of the Territory Subjected to Radioactive Contamination as a Result of the Chornobyl Catastrophe" and "On Status and Social Protection of Population Suffered from Chornobyl Catastrophe".

On July 23, 1991, the Cabinet of Ministers of Ukraine adopted Decree № 106 "On Implementing the Ukrainian SSR Verkhovna Rada Decrees "On the Legal Regime of the Territory Subjected to Radioactive Contamination as a Result of the Chornobyl Catastrophe" and "On Status and Social Protection of Population Suffered from Chornobyl Catastrophe", which identified a series of measures to implement the current legislation on public protection against adverse factors of Chornobyl Disaster and mitigation of its consequences, as well as listing settlements referred to the radioactive contamination zones (numbering 2293 settlements)

It should be noted that the Concept and the Chornobyl laws originally featured essential inconsistency and internal conflicts that drew Chornobyl law experts' attention [7-12]. Thus, the Concept initially states that the system of countermeasures on territories with high-level radioactive contamination is not efficient (while not specifying what particular countermeasures are meant), which may cause a drive for resettlement, and the statement is followed by a proposal to implement a system of countermeasures on territories with lower radioactive contamination levels. Experts are well aware that countermeasures are more efficient on territories with higher contamination levels. Therefore, the Concept puts forth measures known to be inefficient a priori.

Furthermore, according to Clause 1 of the Law of Ukraine "On the Legal Regime of the Territory Subjected to Radioactive Contamination as a Result of the Chornobyl Catastrophe" [13], the territories contaminated due to the Chornobyl Disaster include those whose residents could be exposed to a dose over 1.0 mSv (0.1 rem) a year. A semantically similar statement is present in Clause 3 of the Law of

Ukraine “On Status and Social Protection of Population Suffered from Chornobyl Catastrophe” [5] which provides for residence and work for people without radiological restriction if their additional exposure dose due to living on the affected territories does not exceed 1.0 mSv (0.1 rem) a year. These regulations are in perfect compliance with respective international recommendations [14, 15] and Ukrainian national nuclear legislation provisions coordinated with those recommendations [16, 17]. However, among radioactive contamination zones, Clause 2 of both laws mentioned identifies an enhanced radioecological monitoring zone (the so-called 4th zone) as the territories with soil contamination density exceeding the pre-Disaster level by 1.0 to 5.0 Ci/km^2 for cesium isotopes, or 0.02 to 0.15 Ci/km^2 for strontium, or 0.005 to 0.01 Ci/km^2 for plutonium, provided the calculated effective exposure dose with radionuclide migration coefficients for plants and other criteria taken into account exceeds a dose that had been received by the individual in the pre-Disaster period by 0.5 mSv (0.05 rem) a year.

That means some legal clauses consider the enhanced radioecological monitoring zone to be a territory unaffected by radioactive contamination and requiring no any radiation factor restrictions regarding population residence and activity, while according to other clauses of the same laws, this territory should undergo radiation protection measures and its residents receive benefits and compensations for living on a radioactively contaminated territory with relevant activity restrictions applied. By official statistics [4], the population of radioactively contaminated zones totals around 2.3 million people, of which 1.6 million are residents of the enhanced radioecological monitoring zone. It also has to be noted that by the Concept, the soil radionuclide contamination density is used as a temporary decision-making criterion until an individual effective exposure dose will be ascertained for the residents. Beginning in 1991, dosimetric passportization of settlements affected by the Chornobyl Disaster has been carried out in Ukraine on a regular basis. Individual effective exposure doses for residents of those settlements (so-called passport dose) and their dynamics are regularly published and are well known [18-27]. Today, as a result of the natural environment attenuation processes and counter-measures undertaken, the radionuclide content in the environment objects has gone down by 37% and by 1.5 – 2 and more times in agricultural produce, which is reducing in its turn the public external and internal exposure dose by 2-3 times as is reflected in the changed distribution of settlements by passport dose levels, see Table 2.

For comparison, the same Table refers the number of settlements in each radiation contamination zone according to the Cabinet of Ministers of Ukraine Decree № 106 dated July 23, 1991 that remains in force as of today except for 6 settlements in Volyn and Rivne Regions, which, according to a relevant

Table 2. Distribution of settlements (referred to radiation contamination zones accordingly to acting legislation) by additional exposure dose derived from dosimetric passportization data.

Year of passportization	Average exposure dose in the settlements, (mSv per year)			
	< 0.5	*0.5-0.99*	*1.0-4.99*	*> 5.0*
1996	1307	333	507	6
1997	1350	359	443	9
1998	1332	375	440	7
1999	1375	380	397	9
2000	1417	298	440	6
2001	1455	314	389	5
2002	1471	317	372	3
2003	1538	338	285	2
2004	1551	410	202	0
1991, Directive № 106 of Cabinet of Ministers	-	1290 (zone 4)	835 (zone 3)	92 (zone 2)

enactment [28], were transferred from the compulsory resettlement zone to the guaranteed voluntary resettlement zone category. From Table 2 it is evident that there are contrasting differences between the regulatory reference of the settlements to the zones of radioactive contamination and dosimetry realities of today. But now there is no approved mechanism for altering settlements radiation contamination zone attribution with the issue itself having lost its validity, becoming merely a political one instead.

Chornobyl legislation experts highlight one more detail. Up to 1998, NRP-76/87 national radiological protection standards had been in force in Ukraine stipulating that the permissible exposure dose for residents of the 30 km zone around NPPs in operation (Category B) be 5 mSv a year. Therefore, zone 4 and 3 residents enjoyed exposure dose reductions and were given benefits and compensations even provided the exposure dose did not exceed 1 mSv and 5 mSv per year respectively, while residents of zones neighbouring operating NPPs could be exposed to doses up to 5 mSv a year without any compensations, which entailed legal discrimination and social injustice [9].

National reports dedicated to the Chornobyl Disaster 10th and 15th anniversaries [2, 3] contained cautious criticism of the decision to resettle residents of the contaminated territories, especially in the period after 1990. But the national report is a documentary genre where criticism apparently has to be cautious. Although the paper [9] treated both the very idea of resettlement (which itself makes the key point of the Concept) and the way it was implemented with severe criticism, the present author only concluded that resettlement as a countermeasure turned out to be totally unjustified in terms of averted exposure doses and economical and socio-psychological aspects. Resettlement, the way it was stipulated by the Concept against the radionuclide area contamination, is not consistent with the scientific basics of human radiation protection– exposure dose is the only thing to measure potential adverse effects.

The research generally indicates that the Concept and respective laws were found not to abate but to further sharpen the public concern about their and their families' lives, which itself negatively affected their health. Moreover, benefits and compensations depending on the exposure dose value (radionuclide contamination of food and territory) stimulated the recipients of benefits to try and keep the exposure dose received instead of acting to reduce it. That is another negative aspect of the aforementioned laws [9].

According to experts, one essential drawback of the Concept and laws adopted on its basis is the prevalence of protectionist measures in respect to residents of contaminated territories rather than stimulating the residents' activity to reduce their exposure dose load [10].

In recent years the Government of Ukraine has made attempts to lift this conflict between the current legislation and economical capability of the country on the one hand, and between the level of social security offered to affected people and growing socio-psychological tension on the other, yet with no appreciable effect. Numerous claims to make changes and additions to the Chornobyl Catastrophe associated laws proposed to eliminate the controversies between certain clauses and regulations of the laws, to bring the current legislation in compliance with economical ability of the country and to set up a system of comprehensive security for the affected people, were rejected by relevant committees (formerly permanent commissions) of the Ukrainian Parliament under the pretext of incompliance with the effective Concept. It urged specialists to elaborate a new document as a basis for revision of relevant laws. For example, a document was prepared and approved by the Ukrainian Government, and was passed to the Verkhovna Rada in 1997 and 1998 for ratification, but in late 1999 it ended up to be withdrawn by the new government for validity check and further elaboration.

The last version of the Concept defining public security provisions in relation to the Chornobyl Disaster consequences was based on the internationally and scientifically acknowledged radiological criteria and recommendations substantiated by experience and knowledge that domestic and foreign specialists had built up in different fields over years of practice in mitigating the Disaster consequences.

Understanding the importance of the Concept, the Verkhovna Rada of Ukraine with their Decree "On Parliamentary Hearings Dedicated to the Chornobyl Catastrophe 14th Anniversary" recommended the Ukrainian National Academy, Academy of Medical Sciences, and Academy of Agrarian Sciences to consider the draft Concept. The presidiums of all the mentioned academies supported it as a basis to further improve the current legislation.

In 2000-2001 the Government of Ukraine made more attempts to submit the new draft Concept for consideration by the Verkhovna Rada, but its committees' resistance resulted in the document being never discussed in the session hall. The story ended by the Cabinet of Ministers of Ukraine issuing a Decree dated 25.07.2002"On Approval of the Draft Concept for the Law of Ukraine "On Amending the Laws of Ukraine "On the Legal Regime of the Territory Subjected to Radioactive Contamination as a Result of the Chornobyl Catastrophe" and "On Status and Social Protection of Population Suffered from Chornobyl Catastrophe".

One more aspect worth noticing is a significant difference between exposure dose-based compensation amounts stipulated by the relevant Chornobyl laws and those provided for by the Nuclear legislation of Ukraine. The Law of Ukraine "On Protection of People against Ionizing Radiation" [16] contains Clause 19 "On Compensation for Exceeding of Basic Annual Exposure Dose Limit" providing for the yearly basic exposure dose limit excess based compensation to be given to people residing or temporarily staying on the territory of Ukraine in case of radiation contaminated food and drinking water forced to consumption, radiological insecure living, work and study conditions, which is completely attributable to the Chornobyl Disaster context.

The mentioned clause stipulates that compensation for the exceeding of annual basic exposure dose limit comprises 1.2 times of an individual minimum non-taxable income amount for every millisievert in excess of the set permissible radiation limit. According to the Law of Ukraine "On Personal Income Tax" [29] (Paragraph 22.5 of Clause 22.) in case other legal regulations refer to the minimum non-taxable income, the amount of 17 UAH is taken as a basis, except for administrative and criminal legislation regulations in the part of crime or law violation qualification for which the minimum non-taxable income amount is set at the level of a social tax privilege defined by Subparagraph 6.1.1 Paragraph 6.1 of Clause 6 of the Law for a given year (including stipulations of Paragraph 22.4 of Clause 22 of the Law).

Thus, according to the Ukrainian nuclear legislation, the yearly basic exposure dose limit excess based compensation makes 20.4 UAH for every millisievert in excess of the set permissible radiation limit (the set limit for population is 1 mSv a year). Getting back to Table 2, one can easily reckon that, in case residents of the affected territories were given compensations under the nuclear legislation in compliance with the 2004 dosimetric passportization of settlements attributed to the radiation contamination zones, only residents of 202 settlements would be entitled to claim compensations for excessive radiation (exceeding the basic dose limit) and this compensation amount would not exceed 81.6 UAH per individual a year as far as the maximum dose did not exceed 5 mSv and basic dose limit excess was no more than 4 mSv.

Total compensations amount provided by the Chornobyl legislation for residents of settlements belonging to radiation contamination zones happen to significantly exceed yearly basic exposure dose limit excess based compensation stipulated by the nuclear legislation which violates social equality principle.

To sum it up we can draw a conclusion that the Chornobyl legislation, despite its high humanistic trend, is inconsistent and contains significant internal controversies:

- directed at preserving the status quo and does not provide for internal mechanisms of adaptation to radiation situation changes on contaminated territories; prioritizes protectionist measures in respect to people rather than stimulating the people's activity aimed at their radiation load reduction, causes social passivity and paternalistic mood among contaminated regions residents;
- the scope of benefits and compensations stipulated by it is ungrounded from the perspective of radiological protection; total cost of its provisions is out of proportion with the economical ability of Ukraine;
- its provision for a yearly basic exposure dose limit excess based compensation does not comply with the nuclear legislation of Ukraine which is in violation of the social equality principle.

Thus, the Chornobyl legislation could never become an efficient tool of eliminating the Chornobyl Disaster consequences.

In our opinion one of the root-causes of this situation is that, trying for a lengthy period of time to cover up for their reluctance or inability to normalize the situation on the contaminated territories by means of stimulating the residents social mobilization and backing economic and business initiatives, authorities of all levels (however not the State power in general as there were officials who sought ways to improve the situation), perhaps even not being aware of it themselves, happened to be objectively interested in hyperbolizing the radiation threat. It was easier to hide their mistakes and inertia in a dense shade of the boosted nuclear monster, exposing the public to something that was so loved by our people - their uncompromised fight for enlarging and widening the benefits and compensations. Besides, as stated in [11], the Chornobyl legislation improvement issue runs into a resistance on behalf of a number of prominent Ukrainian scientists, mainly in medical sphere who seem to be subjectively interested in the problem conservation.

Do we see a way out from this complex situation? Well, the exit itself is not on the horizon yet, but the direction to it can be discerned. There are a number of possible options and all of them call for political will to bring order to the Chornobyl legislation on behalf of the Parliament, Cabinet of Ministers and the President of Ukraine.

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Solving the social problems caused by the Chernobyl catastrophe: 20 years is not enough

Volodymyr Tykhyy*

Introduction

Nearly twenty years that passed after the Chernobyl nuclear disaster call for deep investigation of its consequences for people who were affected - usually referred to as "Chernobyl sufferers". Approximate numbers (it is believed that exact numbers will never be known) reveal a real humane catastrophe:

- more than 600,000 participated in the re-construction of the nuclear power plant itself and clean-up of the area ("**liquidators**" of the aftermath of the accident; more than 300,000 of them live in Ukraine - see details below);
- more than 350,000 were resettled, of them about 120,000 evacuated during the first period, including 49,360 inhabitants of the city of Pripyat on 27 April 1986;
- several millions live on contaminated lands since 1986.

Fortunately, it is not a scale of a major war, but it is a scale of a regional military conflict involving several countries...

Economic sufficiency, optimal health, reasonable housing, access to education and recreation, and happy relationships are some of the fundamental needs that constitute the essence of a social well being. The importance of it is recognised by governments and policy makers. Governments and policy makers are those who influence social conditions of living to the greatest extent, especially in strongly regulated systems like the system of "developed socialism" that existed in the Soviet Union and which dominated a great deal the life in Ukraine in the first half of 90th. What impact has the Chernobyl catastrophe had on the social well being of affected population?

Due to limitations on the scope of this paper, we will not discuss health-related and children-related issues, because these are separate big and most complicated topics.

Chernobyl had various repercussion not only for three most seriously affected nations (Ukraine, Belarus, Russia), but all over the world. In 2002, a UN report "The Human Consequences of the Chernobyl Nuclear Accident. A Strategy for Recovery" [1] was released. However, due to the goal of that assessment the report is too general and in some aspects controversial (see, for instance, comments by Nesterenko, Yablokov, Grodzinsky[2]). The most comprehensive account of events in Ukraine that followed Chernobyl disaster could be found in the book published by the National Academy of Science of Ukraine in 1995-1996 "Chernobyl Catastrophe", edited by Academician V.G.Baryakhtar [3]. The positive and negative feature of this book is that almost all papers on social protection measures were written by those who implemented them: thus, the papers comprise good factual data, but they reflect positions of respective government agencies that provided assistance and not the opinions of recipients. Since different authors wrote different sections in the book, references are given accordingly. The Institute of Sociology of the Academy of Science of Ukraine has published detailed reports of scientific investigation of social, economic and psychological consequences of Chernobyl Catastrophe[4].

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In this paper we will briefly outline only problems of those who live in Ukraine - liquidators, resettled, those who still live in contaminated areas. The issue of several thousands workers of the Chernobyl nuclear power plant (NPP) - veterans from before 1986 and newcomers - needs a separate research, as it was developing first in the unique "closed" system of the Soviet nuclear industry, and later under the influence of a fierce struggle between international community trying to close Chernobyl NPP and the Ukrainian government trying to smooth over numerous negative consequences of closing the NPP. Closely linked to their problems is the history of the city of Slavutych (population 26,000, built in 1987-89 chiefly to house personnel of Chernobyl NPP): all pains and tensions caused by changing social protection policy and by the process of closing Chernobyl left their traces here.

For each affected community, each family and individual the disaster had various social, economic, health and psychological impacts. From the first days after the catastrophe the state (first the Communist Party and the Government of the Soviet Union, later Governments of independent states) played a major role in attempts to protect the affected population and to provide compensations for incurred adverse impacts. An outline of these attempts (adopted legislative acts, economic decisions, social policies, direct international assistance etc.) will be discussed in this paper, as well as results of implementation of the planned measures. International assistance to the city of Slavutich, which was quite significant and which went hand in hand with the political pressure on the Ukrainian government - to close down Chernobyl NPP - will not be discussed in this paper.

Evolution of the social and political system of Ukraine between 1986 and 2004: brief outline

The present-day Ukraine (a 48-million nation in Eastern Europe) at the time of Chernobyl catastrophe was a republic within the Union of Soviet Socialist Republics, USSR. The Communist Party ruled the country in the so-called "command and control" manner. In 1985, attempting to solve numerous internal and external problems, a new dynamic leader of the USSR, Mikhail Gorbachev, launched "perestroika" - reconstruction of the whole system. This eventually led to a collapse of the USSR and resulted in many hardships and successes for the people of the country.

The social and political system of the USSR at the time of Chernobyl catastrophe - known as "developed socialism" - was fully centralised with almost all important decisions taken in Moscow, with practically 100 % state ownership of natural resources, bank system, industrial enterprises, infrastructure, health care and educational systems, etc. Civil society virtually did not exist: municipalities, non-governmental organisations (NGOs), even church were all under the strict control of the state.

This situation has gradually changed over two last decades: multi-party political system developed with decisions taken by the Parliament, the nationally elected President and the Cabinet of Ministers appointed by them; independent from the state business sector has been created and flourishes; third sector emerged with hundreds of *de-jure* and *de-facto* independent NGOs, protecting civil rights and interests of their members; administrative reforms provide more and more power and financial resources to communities.

Several events have had deep influence on Ukrainian society in the last quarter of the XXth century. We can list them starting with Chernobyl catastrophe (1986), which dislocated hundred of thousands of people, created the state of anxiety in millions, and placed such a burden on the national economy and finance that it obviously hastened the collapse of the USSR.

Disintegration of the Soviet Union that followed the unsuccessful attempt of *coup-d'etat* in 1991 led not only to the feeling of instability, but also to huge economic problems with eventual impoverishment of some 90 % of Ukrainian population during 1992 - 1994. In some periods monthly inflation was higher than 100 %, and all savings completely disappeared with the collapse of the State Savings Bank of the USSR. All this created the feeling of insecurity and pessimism.

Still this was not the end of hardships, because in mid-90s privatisation of the state property was launched, with members of political and economic "elites" becoming incredibly rich, while the majority of "ordinary" people becoming poor. During 90s a new political and economic system emerged. After the stepping down of the President Leonid Kuchma in January 2005, who was elected in 1994, this system was nicknamed "kuchmizm". The system was characterised by 50-60 % share of "black" and "grey" economy, mass export of capital and total corruption in all spheres of social and economic life. Transparency International index of Ukraine, which was 69th of 85 countries when Ukraine first appeared on the list in 1998, became 87th of 90 countries in 2000 (for comparison, Russia was 76th in 1998 and 82nd in 2000)[5].

During that period, sophisticated "schemes" of avoiding taxation were invented, and this led to serious budget problems. Many opportunities for avoiding taxation were created by the government itself - most common were special "preferences" which allowed some companies and territories not to pay certain taxes, custom duties and other "mandatory" payments to the budget (the reader may guess how these companies and territories were selected). To give the feeling of incurred budget losses, we can mention that when a new (appointed after the "orange revolution" of 2004) government cancelled these preferences, the resulting planned additional income was 8.7 billion hryvna (US$1.64 billion) - more than 10 % of the budget. Various preferences were created by the Chernobyl legislation as well, but most of them were annulled several years ago. Of course, all this did not help in solving numerous problems of Chernobyl sufferers. Only in the very end of 1990s the state finances became stable, as well as the funding for Chernobyl programs.

Additional circumstance which seriously aggravated the situation in all rural areas - and more so in those affected by Chernobyl contamination - were slow and inconsistent reforms in agrarian sector. These reforms included reorganisation of soviet collective farms and state farms into "collective agricultural enterprises" and joint-stock companies. Old system disintegrated, and the new one served only interests of new owners - usually former "red directors". Limited opportunities opened for establishing independent farms, but without governmental supports such attempts were often unsuccessful. The unresolved issues of land ownership and agricultural land use were hindering transformations in agrarian sector, and the situation changed only in 1999 when the special decree of the President was issued. With it, and with the following decree of 2000, a market system in agrarian sector started to function and the population of the rural areas obtained framework for implementation of economic initiatives that possibly can lead peasants to prosperity.

Legislation, number of sufferers and budget expenditures

Chernobyl-related legislation and government policy for social assistance to affected people

Despite the fact that the USSR was a country with extensive military and civil nuclear programs, a country with several tens of nuclear power reactors in operation, there was no law on the use of nuclear energy. In cases of nuclear accidents that happened before Chernobyl, problems were settled behind the closed doors of responsible ministries - of course, without any public consultations. Social issues were settled in the same manner, and usually sufferers of the accidents were ordered to sign a special commitment of non-disclosing the matter: this was a condition *sine qua non* for obtaining assistance and social benefits.

When the Chernobyl catastrophe occurred, there was no existing legal base and no existing policy of handling the problem. All decisions were taken *ad-hoc* at the highest level of the government. Because there were very limited possibilities of evaluation of real and expected doses for each affected community (due to enormous scale of affected territory and population, the insufficient background and current information, lack of knowledge among those who were taking decisions and those who implemented them, absence of capacities for processing huge amount of radiological data), during the first period of 1986-1989 the decisions were based on the levels of contamination of soil by radioactive substances.

First government decisions after the Chernobyl catastrophe dealing with social problems (evacuation of the 30-km zone, compensations for loss of property, mobilisation of resources and manpower for resettling people etc.) were taken by the Politburo of the Central Committee of the Communist Party and the Council of Ministers of the USSR. Only in April, 1990, the legislative body of the country - the Supreme Council of the USSR adopted a Resolution "On a comprehensive programme to liquidate the consequences of the accident on Chernobyl NPP..."

The law of the USSR, which specified relations between the state and the affected population "On Social Protection of Citizens who suffered from the Consequences of the Chernobyl Catastrophe", was adopted in May 1991 - five years after the accident. Earlier that year, in February 1991 two basic Ukrainian laws were adopted by Verkhovna Rada (Parliament) of the Ukrainian SSR: "On the legal status of contaminated territory..." and "On the status and social protection of citizens who suffered due to the Chernobyl catastrophe".

It should be kept in mind, that Soviet and most of Ukrainian laws are indirect, which means that they define general policy, but later specific regulatory acts are needed to start their implementation. For serious problems such acts are adopted by the Cabinet of Ministers, and this was the case with Chernobyl: the Resolution of the Council of Ministers of Ukrainian SSR № 106 of 23.07.1991, in accordance with the two Laws mentioned in the previous paragraph, specified the list of 86 communities of "mandatory" resettlement and 800 communities in the zones of "guaranteed voluntary resettlement" (it meant that the people willing to move out of this zone were allowed to do so and the government would pay compensation for their property left behind).

But we must remember that on 8 December 1991 leaders of Russia, Ukraine and Belarus signed an agreement to dissolve the Soviet Union. Resources from the "Soviet Union" ceased to come to Ukraine for solving various Chernobyl-related problems. Economic decline that followed forced the Cabinet of Ministers of Ukraine to reduce the number of "voluntary resettlement" communities to 49 in January 1993. The country was unable to provide resources for resettlement to the people from 751 communities that were excluded from the list. However, a huge programme of construction of housing and infrastructure continued.

For the purpose of this paper we will make just several observations on the Law "On social protection..." Naturally it was fully oriented on the soviet system, in which everything was produced by state-owned and state controlled enterprises, almost all goods were centrally distributed and everything was in scarce supply (in "deficit"). Because of this, many provisions of the Law were formulated in this way: "Chernobyl sufferers can receive certain goods and services "in the first place" or "without queue"". With coming of market economy during 90s these provisions lost their importance.

Essential feature of the law is that it **deals both with incurred damage (either loss of health or property, loss of jobs etc.) and with risks which have not yet resulted in real damage (risk of living on contaminated land, risk which poses to liquidators radiation exposure that occurred during their work at and around the Chernobyl NPP). And it is very difficult to determine the real levels of these risks**, although the National commission on radiation protection and other agencies made many attempts to resolve the problem.

Many benefits (especially for liquidators) were defined in the form of preferences - e.g. certain categories of liquidators were exempt from paying custom duties, excise duties, income tax and so on. This led to many abuses and later most of these privileges were cancelled.

Some provisions provided for sufferers' access to subsidies and cheap loans either for individual building of house or for opening own business. These privileges were mostly suspended by the year 2000.

A very large part of the Law deals with health care (which we will not touch here) and recreation. There are several articles, which preview direct payments to sufferers - e.g., addition to pension "for loss of health".

But on the whole the system of social protection was built in such a way that almost all budgetary resources were left in hands of responsible government agencies and then these agencies "served" the needs of sufferers. This was a typical soviet system that provided all opportunities of abuses, because the one who needed assistance had to ask for it. And it was a decision of authorised official to satisfy the request or to refuse - and with a total deficit of everything (as could be seen from the following sections) in no way was it possible to satisfy all requests.

Legislation evolved significantly over the past 20 years. As it is mentioned on the web-site of the Ministry of Ukraine of Emergencies, more than 800 documents regulate now Chernobyl related issues. Basic law - "On social protection..." - was modified 26 times: the first correction made 19.12.91 and the last 03.03.05. The law "On the status of territory..." was modified 8 times. It is clear that new law is needed, but due to the huge scale of territory and very large number of people affected it is hard to expect quick changes.

Number of sufferers

It is very difficult to describe the diverse and big pool of Chernobyl sufferers in a short paper.

Apparently the first are those who are considered sufferers according to the Law. As of 1 January 2002 in a special Data Bank there were data on 2,422,212 persons of a total 3,096,814 people registered by the State Committee of Statistics as Chernobyl sufferers [6]. This comprises roughly 6 % of the population of Ukraine. There are two major categories: 335,785 liquidators (people who worked on liquidation in 1986-1990) and 1,709,146 sufferers (people who live or have lived in contaminated areas). These people are scattered all over Ukraine (see map on Figure 1, bars for oblasts with highest numbers, data from[6]).

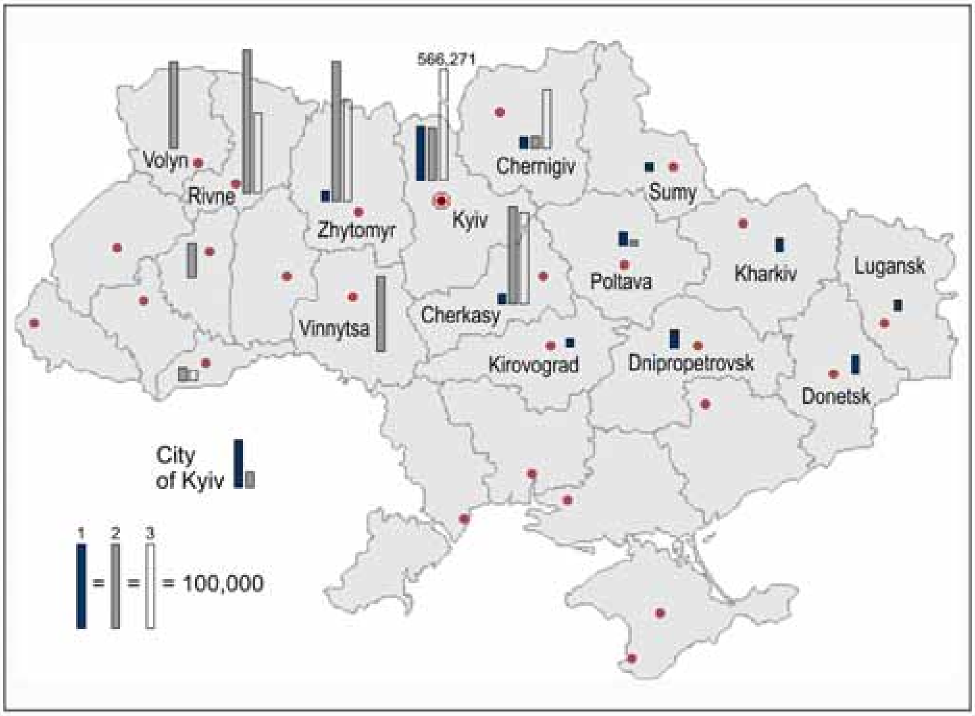

Figure 1. Number of liquidators of categories 1-3 (1), sufferers of categories 1-3 (2) and sufferers of category 4 (3) in some oblasts of Ukraine (bars are shown only for oblasts with highest numbers).

All liquidators and sufferers are divided into 4 categories, and receive benefits according to the category they have. A liquidator, for example, can have:

- category 1 if he/she is disabled (*invalid)* and his disability has causal relation with Chernobyl (this relation is established by an authorised panel of doctors);
- category 2 if he/she worked in the 30-km zone either any number of days before 1 July 1986, or more than 5 days between 1 July 1986 - 31 December 1986, or more than 14 days in 1987;
- category 3 if the number of days is big enough (it's specified in the law) but not sufficient for obtaining category 2.

Sufferers can have categories 1-3 if they live or have lived on the territory of mandatory or guaranteed voluntary resettlement (here again, category 1 is for disabled) or category 4 if they live in zone of "strict radiological control".

Children (evacuated, children who had lived in contaminated areas, or those with at least one parent-liquidator) constitute a separate very large group of 1,048,628.

Among liquidators and sufferers there are hundreds of thousands of those who already incurred damage either to health (number of *invalids* whose diseases have a proven causal connection with Chernobyl catastrophe reached 96,000 by 2002), or loss of property, or loss of family. There are 13,027 families who receive welfare payments due to the loss of provider.

There were doubts as to whether all those who were registered as liquidators indeed earned this status. From January 1997, 388,755 personal files have been reviewed, and 22,708 persons (6 %) were denied the status[6].

Of course there are many people who have been experiencing hardships after the catastrophe, but are not listed in the registries. Of them we can mention members of the families of liquidators, or those citizens of Kyiv and other cities and towns who were waiting in queue (sometimes for decade and more) on a municipal or built by their enterprises flats and houses - and suddenly these flats and houses were given to families evacuated from Chernobyl zone. For thousands of families this meant additional years of life in over cramped conditions. Indirectly, the sufferers are all people of Ukraine who have been paying for liquidation with their tax money.

Dynamics of required and provided financial means

During the first period (1986-1989) the funding for liquidation of the consequences of Chernobyl catastrophe was provided by the budget of the Soviet Union, and only small portion of it was taken from the budget of Ukrainian SSR [7]:

Table 1. Expenditures directed on mitigation of the consequences of Chernobyl catastrophe, million roubles

Year	1986	1987	1988	1989, January-August
From the budget of Ukrainian SSR	-	70.8	76.4	95.4
Total	1585.5	1646.4	735.1	551.2

At that period the official exchange rate was roughly 1 rouble = 1USD. In 1986-1989, main component of social investments was construction of houses and social infrastructure (for evacuated and resettled). There was also significant funding for decontamination of soil and settlements. The volume of construction works done by only one leading Ukrainian contractor - Ukragrobud company - and its subcontractors is given in the following table. (Ukragrobud was a "head contractor", that means that it subcontracted other design and construction organisations as needed):

Table 2. Funding provided to Ukragrobud company for construction of housing and infrastructure for liquidation of the consequences of Chernobyl disaster in 1986-1989[8].

Date of decision of Council of Ministers of Ukraine allocating funding	10.06.86	14.10.86	12.12.86	08.04.87	08.12.88	TOTAL
Allocated funding, million roubles	377.0	31.4	231.9	87.0	14.0	746.7

These figures do not include other construction companies, and they do not include the city of Slavutich, because the leading contractor for Slavutich was "Slavutychenergobud" company of the Ministry of Energy of the USRR. The cost of building of Slavutich is estimated at 490,000,000 roubles[9].

After 1988, there was a general expectation that the problem of resettlement has been resolved, but it became obvious that many more thousand people have to be resettled in the safer environment.

There exist more information on the Chernobyl budget expenditures after the dissolution of the USSR[1].

Table 3. Chernobyl budget expenditure of Ukraine, millions of US dollars

	1992	1994	1996	1998	2000
Social protection	197.3	478.1	545.6	429.1	290.1
Special medical care	6.3	8.8	19.0	8.2	6.4
Radiation control	2.0	2.3	4.4	8.7	2.7
Environmental recovery	-	0.4	0.2	0.2	0.04
Radiological rehabilitation and radioactive material disposal	0.3	0.2	0.2	0.2	0.05
Resettling, housing and living conditions improvement	276.1	205.3	194.1	86.5	13.7
Other expenditures					
TOTAL	**510.8**	**755.7**	**835.2**	**584.7**	**332.7**

It is important to notice that the real GDP of Ukraine was steadily declining in 1990s (between 1991 and 1994 the national income of Ukraine declined by 60 %[10]), and the share of Chernobyl fund in the budget was also declining. However, the size of Chernobyl budget was still on the level of several percents of GDP (4.6 % in 1992, 1.9 % in 1993, 2.2% in 1994[10]). Of course it constituted even higher share in the national budget.

In the same time, the needs of Chernobyl programs were growing. This is clear from the following table[11]:

Table 4. Funding for social protection of Chernobyl sufferers: needed, planned and provided (in million Hryvna)

Year	Average exchange rate of Hryvna[12] $US1 =	Needs according to Chernobyl legislation	Planned in the state budget	Planned, % of needs	Provided funds, % of needs
1996	1.83	2004.1	1150.8	57.4	49.8
1997	1.86	3291.7	1799.3	54.7	36.0
1998	2.45	3474.9	1953.5	56.2	30.2
1999	4.13	4408.0	1310.1	29.7	27.4
2000	5.44	5771.9	1578.4	27.3	27.3
2001	5.37	6731.5	1559.6	23.2	23.2

For example, the state budget of Ukraine (expenditures) for the year 2000 was 33,946.5 million Hryvna[13], and Chernobyl needs were 5771.9 million Hryvna, that makes nearly 17 %. Provided funds amounted to 4.6 % of the state budget.

The gap between the needs and provided funds shows that the national economy was unable to carry the burden of Chernobyl expenditures required by the law. How could it happen? One explanation is that several generations of Parliament members became legislators using in their election campaigns promises to improve the situation for Chernobyl sufferers. So these Parliament members lobbied interests of Chernobyl fund, and probably not only for the benefit of the sufferers, but also to satisfy requests of numerous lobbyist groups who were making good money on Chernobyl related contracts. So far, the Parliament has been unable or unwilling to make fundamental amendments to Chernobyl legislation, and there are indeed serious social reasons for this.

Implementation of social protection measures

Measures aimed at solving economic problems of the sufferers

The area contaminated by Chernobyl radionuclides is agricultural. If we set aside a case of the satellite city of Chernobyl NPP - Prypiat (which we do not discuss in this paper), most economic activities in the area were agricultural or centred around agricultural production (processing of crops and other agricultural products, maintenance of agricultural machinery and infrastructure, transportation of raw materials and products etc.)

Papers and reports dealing with economic consequences of Chernobyl catastrophe usually speak about loss of production: loss of energy generated by Chernobyl NPP, loss of industrial and agricultural output, loss of agricultural lands. But social dimension of all these means loss of jobs, severe decrease in family income, loss of perspectives for future. Domination of publications on consequences for *economic output* is very characteristic both for the soviet era and for the first decade of post-soviet era, when economy was considered much more important than people who were just "work force" for national economy.

In Ukraine, however, even this account of economic losses was not done with necessary diligence. In Belarus, six national evaluations of economic losses caused by Chernobyl on its territory were prepared between 1986 and 1992, while in Ukraine this work started only in 1991[7].

Ability to work and to receive a decent income is a basic social need. After the catastrophe, this ability immediately disappeared for tens of thousands of peasants whose work directly depended on agriculture: their crops were not needed, meet from their pigs and livestock could not be consumed, milk and products harvested in forests were contaminated.

It should be mentioned that during the first period after the catastrophe the state made significant efforts to keep economic life in affected areas running - even if the goal of that work was formulated in terms of "production", and not "saving jobs and family income". To a great degree both went hand in hand, and thus saved the economic potential and the employment.

On the contrary, decontamination measures in settlements proved inefficient[14]:

> "As an example, let's take desactivation of settlements in the zone of "strict" control, which was done by contingents of civil defence. During 4 years, 1.5 million man-rem (120,000 people were involved) and 1.5 billion roubles were used on desactivation. Efficiency of this desactivation was very low. The radiation background was reduced by 10-15 %"

A whole series of agromelioration measures was developed and implemented between 1986-1994 on vast territories: application of lime - 4962 sq.km, application of higher doses of fertilisers - 7301 sq.km, improving meadows and pastures - 6137 sq.km. The intensity of these measures was 2-3 times higher than before the catastrophe. Special measures were developed which allowed production of "clean" crops, production of "clean" meat and milk on contaminated territories[15].

However, the funding provided for these measures were always low (see Table 3 above) - some 1000 times lower than funding directed for resettlement. So, the efforts aimed at keeping the economy running were insufficient and production (and hence the number of jobs) dropped significantly. The area of used arable land in four most contaminated oblasts dropped by 6.5 - 11.3 %. It is impossible to find in published materials information about creation of new (for this area) sectors of employment. It is hard to say whether this was possible - from the point of view of available humane potential, traditions and economic practicability, and only attempts could have provided an answer.

Only one new sector of employment emerged: control of radioactive contamination. As of September 1995 778 radiological laboratories were in operation only in the system of the Ministry of Agriculture and Food Production of Ukraine[16], and there are other ministries and state committees. It is important, of course, but for local people information about radioactive contamination can be useful only if contaminated food products could be substituted - and usually this is not the case.

Equally serious problems waited evacuated and resettled on the new territories. There is no information about new industrial facilities, farms, greenhouses and the like in the long lists of what was built - only houses, schools, hospitals, roads etc. How could people make their living there, if jobs were in scarce supply in most areas even without Chernobyl resettlers?

In the Law " On the status and social protection..." there were provisions for small loans "to start small business or individual farm", but there is no information on how many people were able to use their chance. Apparently not too many.

It seems that only one business opportunity was intensively used until it was banned in 1995 - duty and excise free import of some goods (like vodka) on contaminated "Chernobyl" territories. But there is no information about benefits created by these activities for the territories and local people (and, respectively, about loss of income of the state budget).

Housing and social infrastructure

Construction of cottages, apartment houses, housing and social infrastructure (water pump stations, schools, kindergartens, hospitals, outpatients health centres, roads, gas supply pipelines etc.) was a major investment in the post-war period. As already mentioned, in early 90s annual expenditures for construction of houses and social infrastructures reached several percents of GDP. Total figures of construction between 1986-2000 are summed up in table[1]:

Table 5. Housing and social infrastructure construction, 1986-2000

Houses and flats	28,692
Schools (number of places)	48,847
Kindergartens (number of places)	11,155
Outpatient health centres (visits/day)	9,564
Hospitals (beds)	4,391

The main effort was undertaken by August 1986, when 90,784 people were evacuated[17]. During 1990-1991 13,658 people were resettled from zones of mandatory resettlement. In all, by the end of 1991 105,000 were evacuated and resettled in mandatory order, and 58,700 people moved from the zones of "guaranteed voluntary resettlement" and other contaminated zones.

But the programme of resettlement continued, and by June 1996 additional 7,864 families were moved from zones of mandatory resettlement, while 5,852 (of them 1,426 families with children) were still living in these zones. It should be noticed that according to a special survey conducted in summer of 1995, only 56 % of families living in zones of mandatory resettlement were willing to move out[17].

By the end of 2002, 1612 families still lived in the zones of mandatory resettlement, of them 762 families refused to be resettled. During 1990-2002 13,787 families were resettled from the zones of "guaranteed voluntary resettlement"[6].

The figures above confirm that the huge work has been accomplished. The question is to what extent it solved the problem of Chernobyl? And were there other ways of handling these problems? We are not in a position to answer this question, but as it is stated by informed specialists:

> "Unfortunately, the attempt of resettling Chernobyl sufferers into new villages practically failed - at that time they were still hoping that they would be able to return back to their houses in Polissia, and they did not want to settle on new lands. So, the big and hard work of construction workers was in fact used not for what it was intended [8]".

So, the resources were used, and there were obviously many people who benefited - not only Chernobyl sufferers. There are several reasons that could be mentioned. First, major part of resources was not given to sufferers, but was transferred to different government agencies. Officials at all levels were responsible for planning (without consultations with ultimate beneficiaries - affected population). Officials were in charge of contracting construction companies and in charge of accepting their work. Officials were responsible for distribution of houses and flats. In the *Internet* Russian version of the book[3], which could be found on the web site **http://stopatom.slavutich.kiev.ua/1.htm,** there is a page missing in the Ukrainian version (it should be placed somewhere between pp.88 -89), which provides evaluation of the results of the housing construction programme:

> "...more than 500 of built houses were not inhabited by fall of 1986... In Chervonoye village of Yagotyn rayon by 1 June 1988 40 of 65 constructed houses were not inhabited, in Supoyevka village - 53 of 140. Main reasons for this were low quality of construction, unsatisfactory social conditions, absence of jobs for new settlers... When 27,800 inhabitants living in houses built for evacuated were inspected, it was found that part of them had no relation to evacuated. They were local residents and people from other "clean" areas of Ukraine and Russia who improved their living conditions."

Of course, a low quality and unfinished construction means that construction companies were overpaid and construction materials used for something else. Obviously there were a lot of abuses during distribution of houses and flats. At present, it seems unlikely that the truth about all this will ever be found and disclosed.

Compensations to sufferers and personal benefits

Benefits for sufferers have been provided in form of free access to some services (free treatment in sanatoria and rest houses, free or partly reimbursable tickets), privileges (tax exempt status, opportunity to import some goods duty free), access to cheap loans (for purchase of house or flat, or starting small business), easier access to budget-sponsored higher education in monetary form.

Access to loans and tax and custom duty privileges are already mostly annulled, some due to many abuses (it is said that some entrepreneurial liquidators managed to import without paying duty more than 100 cars each before this privilege was cancelled). On the list there are still many benefits which were valuable during the period of socialism, but which in fact lost most of their importance at present, because of the changes in the society, which looked during last decade more like a "wild capitalism".

A very big sector of social assistance is free medical service (annual medical examinations, free medicines and so on) and free health improvement holidays for adults and children. This is arranged between authorised government agencies and sanatoria/rest houses located all over Ukraine. Officials are responsible for signing and paying contracts with sanatoria and "control of the quality of provided services". Vouchers are distributed by various authorised agencies among liquidators, sufferers and children.

The numbers of those who used these free vouchers are impressive (data from[1] and [18], although they do not match precisely).

Table 6. Number of Chernobyl sufferers (1,000 persons) who used health improvement holidays

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Adults	214	160	354	185	96	49	49	37	42	30	25
Children	182	282	320	505	300	401	453	467	482	427	348
Total	396	442	674	690	396	450	502	504	524	457	373

However, due to the insufficient funding only a fraction of those who have rights to use this benefit according to the law, were able to enjoy it. **In 1991, the system served each second sufferer, in 1992 - each third, in 1995 - eighth** (*ibid*.) The question remains whether the funding that was provided from the state budget was used in the most efficient manner. With such deficit of free vouchers all sorts of abuses could happen, and all people who have experience of living in the system of "developed socialism" know what might be a quality of "free services". Also there were little stimuli for sanatoria and rest houses to improve the quality and economic efficiency of their services, because in fact they were not competing on the market - their goal was obtaining a wholesale contract from a government official.

Liquidators of categories 1 and 2 (see section "Number of sufferers" above) have a benefit of free use of public transport in cities and free use of commuter trains. This provision cannot be regarded as really fair, because for a person living in a big city this privilege could amount to some $100-150 a year, while it is useless for someone living in a village. Serious problems with this benefit appear due to strengthening of market system: transportation companies want to be reimbursed for their services, but nobody knows how many rides liquidators make - they do not receive tickets of any sort. Only recently it became necessary for any possessing such benefit to obtain free ticket on commuter trains so now a railway company can count what it spends on Chernobyl sufferers.

Many benefits for sufferers of all categories are paid in monetary form. These payments comprise the biggest share in Chernobyl budget, and they are important for hundreds of thousands of liquidators and people living on contaminated territories.

Those who were evacuated or resettled from the zone of mandatory resettlement, or who moved to clean areas from the zone of "guaranteed voluntary resettlement" have received compensations for lost property: houses and other buildings, crops, livestock, fruit trees etc. This process is ongoing (partly because it involves also heirs of those who were resettled), partly because of significant changes in pricing during past 18 years. In accordance with the laws adopted in 1996 and 2002, compensations paid between 1992-1996 (during the period of galloping inflation) have to be recalculated into current Ukrainian currency (hryvna) and paid to sufferers by 31 December 2007.

People living in contaminated areas receive several forms of compensations. The basis for their calculation is usually minimal salary, which is fixed by the government for each year: in 2004 it was 262 hryvna (about $50) per month. Payments are different for different categories, usually they include:

- monthly payments as compensation for restrictions on the use of locally produced food (30-50 % of minimal salary) for those living in contaminated areas;
- additional annual payments for those who live and work in contaminated areas (1-3 minimal salaries);
- higher salaries for civil servants and workers of budget organisations (like schools, hospitals etc.);
- higher pensions and scholarships.

Liquidators, invalids (disabled, whose disability is caused by Chernobyl catastrophe) and liquidators-pensioners also receive some payments in monetary form (annual payment for recreation, payment for food, addition to pension) and some payments as discounts, e.g. reduced communal payments (water, heat, telephone etc.)

On the whole, regular payments to sufferers play extremely important role for them and their families. Very often these payments are of the same level or even bigger than an average wage a person can earn in his/her locality. Other benefits like health care, sanatoria, free public transport are also important, although there is a need to improve efficiency of them.

Evolution of the national policy and international assistance

Country's policy on liquidation of the consequences of the Chernobyl catastrophe was approved by the Parliament in February 1993 as a "Concept of the national programme of liquidation of the consequences of Chernobyl catastrophe and social protection of citizens for 1994-1995 and for the period until the year 2000". It worth to note that it was not the "national programme", but a "concept" - a legal act of no immediate force, so practical work was regulated by the effective laws.

In 1996 the Parliament turned down a bill "On radiation protection of people", which might had provided a legal basis for national actions. However, in February 1997 the improved version of the bill passed the first reading and in January 1998 the Law "On the protection of man from ionising radiation" entered into force. The Law is not retroactive, but together with the Law "On the protection of population and territories from extraordinary situations of technogenic and natural sort" adopted in 2000 it provides necessary legal basis for potential future nuclear disasters.

The "Concept of the national programme..." mentioned above should have been replaced after the year 2000, and in November 2002 a bill "On the national programme of minimisation of the consequences of Chernobyl catastrophe for 2002-2005 and for the period until 2010" passed the first reading in the Parliament. However, as of March 2005, it has not been submitted for the second reading by the Parliament. Institutional changes are also considered, namely creation of the special State Committee dealing with liquidation of the consequences of Chernobyl Catastrophe (see, for example [19]).

As we already mentioned, international assistance focused mainly on the issues of Chernobyl NPP, including damaged reactor and shutting down of the remaining reactors. Significant support was also provided for managing the 30-km exclusion zone and for the social assistance to Chernobyl NPP workers and the city of Slavutich. Many international organisations, including organisations of the UN system, governments and non-governmental organisations provided humanitarian assistants to Chernobyl sufferers. Detailed account of these efforts can be found in [20].

Among other efforts the UNESCO-Chernobyl Program which was implemented in three countries (Belarus, the Russian Federation and Ukraine) should be mentioned. It was launched in 1991 and terminated in1997. Although the work was fully relevant to the sufferers' needs, and more than $9,000,000 was mobilised, the results did not have a follow-up (except for one project), and the running costs and costs not directly benefiting the Chernobyl victims were very high (executive summary of the external audit of the programme[21]). Anyway, this effort could not influence the situation significantly - during that years annual budget expenditures of Ukraine on social Chernobyl programs reached US$200-500 million (see Table 3).

In Ukraine, with the support of the UNESCO-Chernobyl Programme, three centres of social-psychological rehabilitation of population were established by the Ministry of Ukraine of Emergencies in 1994 and two more centres in 2000. These centres provide advice and psychological help to most socially unprotected groups of population (liquidators, resettled, disabled, unemployed, young people). A goal of the work of these centres - abatement of general tension and alarm among population, professional orientation for young people and unemployed, environmental education and information activities. More than 50,000 people appeal to these centres each year[22].

In 2002, UNDP in Ukraine, along with the Ministry of Ukraine of Emergencies and Affairs of Population Protection from Consequences of Chernobyl Catastrophe, launched Chernobyl Recovery and

Development Programme (CRDP). CRDP addresses issues highlighted in the joint UN report[1]. CRDP is currently funded by the UN and the governments of Switzerland, Japan and Canada. So far over $3,000,000 was acquired, and the programme is expected to run until 2007[23].

CRDP components include policy development, community development, social development, economic development and environmental recovery. Until the end of 2004, the programme worked in 63 communities in 3 oblasts of Ukraine (Kyivska, Zhytomyrska, Chernihivska) and from 2005 6 more rayons will be added. Over 70 community development projects were implemented in 2003-2004, with funding coming from communities themselves (20 %), local governments (50 %), CRDP project (30 %) and other sponsors (10 %). More than 90 community organisations were formed and received support in the form of training, development of networks of business services providers and initial grants. The programme also provided information materials on environmental recovery and development opportunities in agriculture, water supply, energy efficiency and other issues.

Conclusions

A huge system for social protection of Chernobyl sufferers has been built in Ukraine during 19 years. In principle it is a "soviet-type" paternalistic system, in which government officials take almost all decisions, and sufferers are "dependants". Major part of financial resources stays in hands of responsible government agencies. The figures of budget lines (after 1995 when the published state budget became more detailed) confirm this conclusion. E.g., in 1995 money allocated for those "who are moving out of Chernobyl zone individually, and state construction programme for liquidators of category 1" comprised 16 % of money allocated for state construction programme (for Chernobyl sufferers); in 1996 - 38 %; in 1997 - 44 %; in 2000 - 39 %. Apparently this ratio was even lower before 1995. (It is not clear how much was paid directly to people for individual building, and how much was spent for state-contracted construction of housing for sufferers of category 1).

Similarly, with health improvement holidays main part of money is spent by government agencies. For example, average price of one recreation voucher in 2000-2004 was around $150, while direct annual monetary payment for "recreation" to each liquidator of category 2 was equal around $5. Compensations for unused holidays were also several times lower than the price of recreation voucher, and they were not always paid.

The system that emerged probably gives people some feeling of safety, but it does not stimulate initiative. As sociological investigations show, an attitude of "dependant" became a common feature among Chernobyl sufferers[24]. People do not take initiative in their hands, and often do not want to take such initiative. Social monitoring in contaminated territories and among sufferers is needed; it could have helped in finding solutions. Such monitoring was started in 1997, but after several years discontinued on the initiative of the Ministry of Ukraine of Emergencies (ibid.).

It is clear that the current system of social assistance to Chernobyl sufferers needs serious reforming, but this reform cannot be abrupt due to very big numbers of those which depend on this system and the fact that many people, excluding children, are not at all young - an average age of liquidator in 2004 was 52 years. We would agree with the conclusion of the UN Report[1] that several years of preparation are needed. The Report proposed a ten-year Recovery Phase of initiatives:

> "The new approach should focus on enabling the individuals and communities affected by the disaster to enter fully into society by taking control of their own lives and acquiring the means for self-sufficiency through economic and human development" (ibid.).

New and much more significant efforts are needed for careful investigation of the current situation and formulation of possible solutions. All this should be done in an open and transparent manner and with intensive public consultations. Only after this, the needed changes to the system could be made without creating additional psychological stress for sufferers and serious risk for the stability of the social situation (we should learn lessons from Russian experience with monetarization of benefits in the beginning of 2005).

Those who formulate the state policy of social protection of Chernobyl sufferers should not concentrate on struggle for higher budget allocations (which is probably impossible), but on finding ways of better use of available resources with the goal of creating the situation when sufferers and territories become economically and socially self-sufficient.

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Case study: the town of Poliske, Kyiv oblast

> **Poliske (Russian spelling Polesskoye) - a settlement (town) in Kyiv oblast, centre of Poliske rayon. Population 11,300 (1986). Sewing, furniture, flax processing factories. Cannery. Production of construction materials, logging and lumber processing.**
>
> *(Ukrainian Soviet Encyclopedic Dictionary, 1987).*

The town of Poliske is located 55 km to the SW of Chernobyl NPP, on the river Uzh, in geographical province of Ukrainian Polissia. The region is known for its ancient and unique culture. The town (known as Khabne before 1934) was first mentioned in written documents in 1425.

(As it was shown by later investigations, the town lies on the Southwest trace of Chernobyl fallout, with contamination by Cs137 between 15-40 Ci/km2 and more. In 1987-88 scientists (who were closely involved in drafting the boundary of the 30-km zone back in 1986) told the author of this paper that they knew that Poliske should have been evacuated, but a town with a developed infrastructure was badly needed to serve various logistical purposes - laundry, etc. - and thus it was decided to leave it outside the zone. Moreover, nearly 28,000 people from Prypiat and evacuated villages were temporarily stationed nearby Poliske between 27 April - 5 May 1986[25].

A secret report, prepared 25.05.86 by the USSR State Committee on Hydrometeorology, listed Poliske among 15 settlements where the level of gamma-radiation on 10 May 1986 was between 3-5 mR/h. Settlements with levels over 5 mR/h were subject to "temporary resettlement"[26], which in effect turned out to be permanent).

In 1986 and later - in 1987-1989 - when many villages were resettled, the town was not evacuated. Instead, a massive decontamination effort was undertaken: replacing roofs and fences, removing contaminated asphalt and paving roads, squares and school yards with new asphalt etc. These works were executed by men aged 30-40 years liable for military service (nicknamed "partisans"), who were drafted for "temporary military service". Effectiveness of this "decontamination" proved to be insufficient for making living conditions safe.

(In the fall of 1988, when the author worked in Poliske conducting yard-by-yard measurements of soil contamination with caesium, he had a chance to present some results and to talk to the Head of Rayon administration. Results clearly showed that contamination exceed all existing limits, but the Head of Rayon insisted that "It is our land, we were born and we will live on it, and we will stay here". It is hard to say what were his reasons to insist on this position - local patriotism, underestimation of danger, willingness to obey orders or some personal agenda. His own position could have been important - he was a Member of the Supreme Council (the Parliament) of the USSR, and that meant high level of authority. Of course there were no consultations with the public...)

Millions of roubles were invested in social infrastructure - new hospital, a whole district of multi-story apartment houses, natural gas pipelines and gas ovens for individual cottages, summer vacations in "clean" regions for children and adults, - this is an incomplete list of measures undertaken by the state in 1986-1991.

Serious efforts were applied to continue (and even increase!) agricultural production in the vicinity of town and the processing of agricultural products on the town cannery. Looking from present time and knowing what we know now, it must seem at least strange, because processed food products included wild berries and mushrooms, dairy products, vegetables... Milk and meat production, working vegetable gardens, flax growing and processing, logging, production of construction materials - all these activities mean work on soil or in a forest - that is, breathing dust.

In 1996, a special Resolution of the Cabinet of Ministers classified certain places outside the 30-km zone, where working conditions in 1986-87 should be considered equally dangerous as in the zone itself. Among them were Poliske rayon hospital, Poliske flax processing factory, dosimetric stations on the road Dibrova-Poliske-Vilcha, Poliske station for desactivation of vehicles and other machines. Equal status received also workers who were involved in logging in nearby forests, as well as those who worked on reforestation and sowing grass on abandoned lands.

(In the same meeting with the Head of Rayon administration the author also raised an issue of compensations. I argued that these should be diversified according to the living and working conditions of people, and hence potential (and actual) radiation doses. It is easy to understand that a person living on a second floor of a concrete house with tap (artesian) water supply and a central heating receives much lower doses then many others who live in wooden cottages, take water from private water wells in the yard and heat their houses with locally collected firewood. Even bigger difference must be between doses of a tractor driver and an accountant sitting in the office where the floor is moped out five times a day. However, the reaction of the Head of Rayon was straitforward: "We all live in this settlement, so we all must receive same compensations").

By early 90s, when information about the real levels of radioactive contamination in the town became widely known and most people acquired adequate and often exaggerated understanding of radiation related risks, the feelings in the town were close to frustration. People, especially those with little children (there were two schools and three kindergartens) were looking for all possible ways of leaving the town. But they needed permission - without such permission they could not receive compensations for the property left behind, and thus their fortune in any new place would be miserable.

(An international community was well aware of Poliske problems. Thus, for example, in 1991 a Swiss organisation SKH equipped Poliske rayon hospital with modern diagnostic equipment and organised permanent consultations of patients and doctors by Swiss specialists, who stayed in Poliske on shift basis. Many other teams of doctors, experts in dosimetry and radiation medicine visited Poliske).

Despite many efforts to improve the radioecological situation in the town, contamination remained too high. So, the Resolution of the Council of Ministers of Ukrainian SSR (CMU) of 14 December 1989 gave permission to families with children under 14 to leave the town if they were willing to. Two months later in February 1990 followed the decision on mandatory resettlement from Poliske of families with children and pregnant women. But of course there were no free houses and flats to implement this decision immediately... And then at last followed a decisive Resolution of the Council of Ministers of 23.08.90 on "mandatory resettlement" of all population of the town. Later this decision was repeated in the Resolution of CMU № 106 of 23.07.1991 in which the town of Poliske was listed among other 86 Ukrainian communities as destined for "mandatory evacuation".

(In 1990, the author accompanied to Poliske a large delegation of Parliament Members, doctors and journalists from Switzerland. The delegation met with town officials, who told about their efforts to make living conditions safe. Only one MP from Ukrainian Parliament joined his nine Swiss colleagues and 40 journalists for that visit.

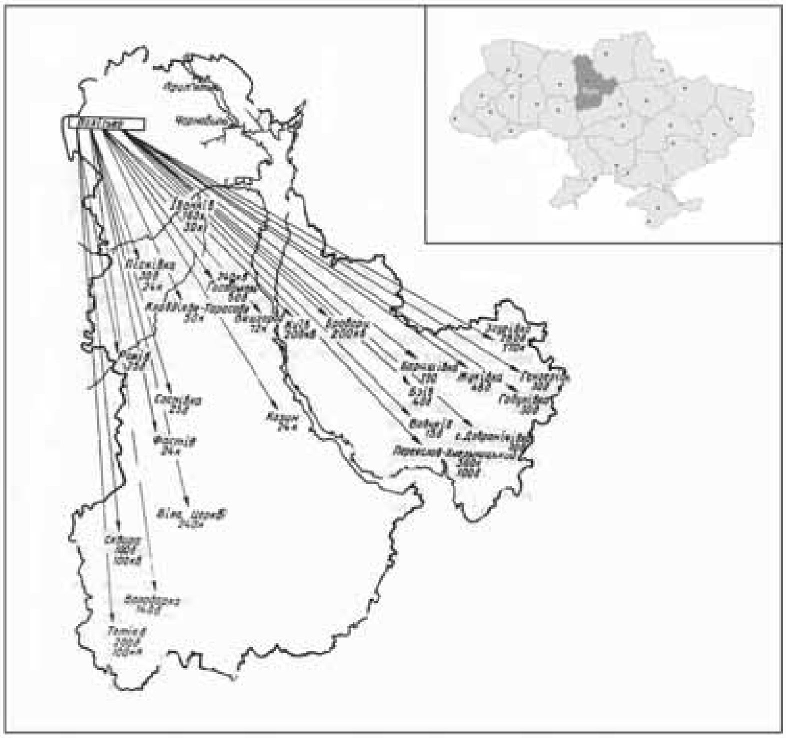

Figure 2. Resettlement of the town of Poliske. Numbers near the name of the town (village) indicate numbers of flats or houses built or provided for Poliske's resettlers.

Later that year a team from Swiss TV (Vladimir Tchertkoff) interviewed teachers at school and kindergarten, and they complained that radiation levels remained high, and that desactivation did not have effect. Parents told about incredible bureaucratic obstacles in obtaining permission for resettlement. It was still a soviet era, and people were not free in choosing the place to live - permits to settle depended upon decisions of the state officials. Later on, in 1998, Tchertkoff's team revisited some people from Poliske - in suburbs of Kyiv and in Kyiv oblast where they lived - and these people told about unbearable humiliation they experienced when the decision on evacuation eventually was taken: they needed to bribe officials to be resettled earlier, to receive better compensation for their property, to choose a place of resettlement...)

Resettlement of some 10,000 people was not an easy job. The government tried to relocate people in large groups to preserve to the extent possible existing families and traditional relations, to make it easier to the people to start new life on new places. But of course there were problems with new construction, demand for new housing was very high. People from Poliske were resettled to 50 different communities in Kyiv oblast (see map from [3] on Fig.2), 9 to 560 families in each. Rarely were they able to renew old traditions on a new land - not only surrounding nature was different, but quite often people from "host" communities were hostile to newcomers. Due to economic hardships of mid 90s, jobs were in scarce supply and no one wanted competitors. Older people who were willing to wait sometimes received better living conditions - they were moved by groups as communes (usually these were neighbourhoods from one or several streets of Poliske). There are several examples, like a half-isolated settlement (which later became a part of the town of Berezan), where people from Poliske have formed a compact commune and live friendly with their neighbours. However, since there are no jobs for younger generation, life in this commune dies out.

After all remaining inhabitants (most of them pensioners) left the town in early 1996, during some period its destiny remained unclear: legally it was still the centre of Poliske rayon. The end to the Poliske's almost 600 years of civil history was enunciated by the Decree of Verkhovna Rada (Parliament) of Ukraine N 204 of 10.07.1996 "On moving the centre of Poliske rayon to the village of Krasiatychi". When the resettlement of the town and all legal procedures were completed, the deserted town was passed under the jurisdiction of the Administration of the 30-km zone.

(Several times after this the author visited Poliske. The view was really pathetic... Of all town's life, militia quarters were guarding the empty town form looters; paramilitary fire brigade was permanently on alert because of numerous fires in forest around the town. Newly-built apartment houses and century-old cottages with new gas-heating ovens were gutted - partly by their owners who removed all that could be used for their new houses (like windows, doors, pipes and toilets etc.), partly by looters. A dozen of older people who refused to leave their houses and self-settlers from nowhere who live in the town depend on bread supply from a bus-shop that made stop in the town once a week. The hospital built and refurbished in 1987-1991 is in operation, but now it serves the needs of the workers of 30-km zone).

Addendum 26 April 2008

The work on this paper was completed in April, 2005. Few significant changes occurred during three years that have passed. Some information and recent data are provided below.

In March 2006 a "State Programme of Mitigation of the Consequences of Chernobyl Catastrophe for 2006-2010" was approved by the Parliament. It lists numerous activities that need to be implemented to improve social situation, including new legislation, systemic approach, scientific justification of measures etc. Main problem with this, as well as with other governmental programs, is that there is no money in the state budget to fully fund it.

It is estimated that the total costs spent by Ukrainian government between 1991-2005 on liquidation of consequences of Chernobyl disaster have reached about 8 billion US$ (Section 3 of the "Programme...")

On 16 April 2008, a hearing dedicated to the 22nd anniversary of the Chernobyl disaster was held in the Parliament of Ukraine. For this hearing, the Cabinet of Ministers of Ukraine prepared "Reference materials". Follow some figures from these "Reference materials", which provide up-to-date information.

The number of Chernobyl sufferers which are registered by the Ministry of Labour and Social Protection was (as of 01.01.2008) 2,376,218, of them: 276,327 liquidators (including 65,361 disabled), 2,099,891 sufferers (including 41,242 disabled and 541,641 children). Compensations, pensions and payments for liquidators and sufferers have been increased during 2005-2007. Budget allocation for social protection and pensions of Chernobyl sufferers for 2008 was increased by 27.8 % comparing to the year 2007, and reached 5,947,200 UAH (approximately US$1.2billion). Unfortunately, inflation and rising food prices will significantly reduce real benefits for sufferers.

In 2007, the total of 147,110 sufferers used "free" health improvement holidays (compare Table 6 above). "Free" vouchers were provided to 15.5 % children and 1.4 % adult sufferers.

The ongoing work on "dozimetric pasportization" (calculation of average doses obtained by inhabitants of particular settlements) indicate gradual decrease in number of settlements where people obtain high doses of radiation. Of 2130 settlements where this work has been performed, the data for 2002-2006 are distributed as follows:

Table 7. Number of settlements according to average calculated dose of irradiation of population

Year	Dose, mSv/year				
	<0.5	0.5 - 0.99	1.00-3.99	> 4.0	Milk > 100 Bq/l
2002	1471	317	368	7	406
2003	1538	334	289	5	339
2004	1551	405	202	5	363
2005	1716	298	112	4	134
2006	1763	294	72	1	84

It becomes clear that status of some settlements could have been revised: thus, in accordance with the effective legislation, there are 86 settlements in the zone of mandatory resettlement, and according to pasportization data there should be 45; in the zone of "guaranteed voluntary resettlement" there are 841 settlements and could be 447. However, necessary legislation for such changes has not been passed yet.

The funding for radiological reclamation of agricultural lands in 2003-2007 was increased to about 5 mln Hryvna/year (in previous years it was about 2-3 mln Hryvna/year). Comparatively larger share of this funding is now allocated for purchase and application of higher doses of fertilizers and production of fodder with radioprotective additives. However, because the total level of funding for improvement of radioecological situation in contaminated areas was reduced after the year 2000 to about 12 mln Hryvna/year (while at least 20 mln Hryvna/year is needed), there are no significant improvements and current activities just keep the situation under control.

One of main issues raised at the Chernobyl hearing 2008 was significant underfunding of commitments which should be funded according to the effective Chernobyl legislation (compare Table 4 above, which shows that only about 25 % of needed funding was indeed allocated. The situation during recent years was either similar or worse). Many MPs stated that it is necessary to "gather political will and pass new Chernobyl legislation instead of outdated law of 1991", but with permanent political instability and populistic habits of all Ukrainian parties it is unlikely that such legislation would be passed in the near future (controversial experience of Russia in this area is also quite discouraging). This means that the government bureaucracy will have same opportunities to manipulate insufficient funds as it has had before.

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Six of Us Left Behind with Mom

Elena Melnichenko
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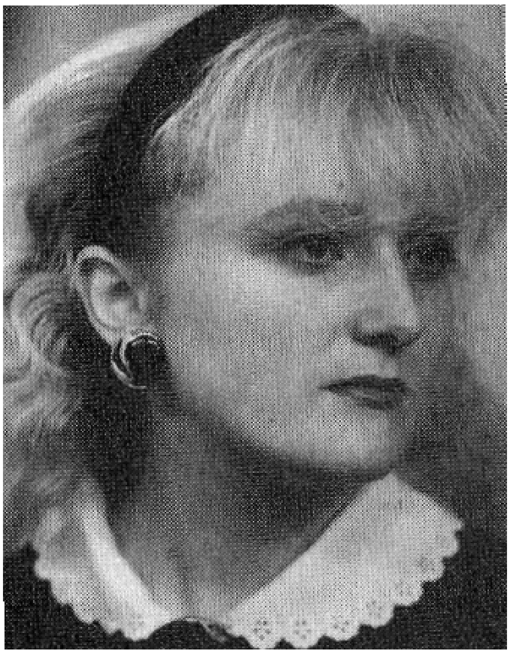
Dzerzhinsk, Belarus



My life since childhood has been full of sadness and misfortune. I was in second grade when everything happened, and since then I have witnessed the people's suffering and sorrow and have myself had to endure it, together with my family.

We lived in a village called Pogonnoe when the accident happened. Our family was very large.

I remember that April morning. It was a sunny and warm day. The grownups hurried to work and children ran to school. It was clear and bright outside with everything green and birds singing everywhere. New leaves were already appearing on trees. The sun shone brighter with the coming of spring.

That day I went to school but soon I found it unbearable to keep sitting at my desk. The other children also felt their heads spinning and intense pain in their eyes. Everyone felt heavy and drowsy. We could not understand what had happened but it was definitely out of the ordinary.

Nobody could ever suspect what a fearful thing had happened not only to us but also to our whole village. Evacuation started after a few days. It was a horrible scene that even now makes my heart ache. Children cried and it was difficult to move the elderly who had deep emotional wounds as they faced leaving their homes and village behind and going somewhere they did not know.

We were told to take only what was necessary for a few days. Some people did and some did not. Some just stood there not knowing what to do since we never had such an experience. People felt only confusion and despair. And what amounts of tears were shed!

We were taken to Gomel where we were examined for radioactivity and told that our clothes and shoes were highly contaminated. They were all taken from us to be incinerated. Then we were put into hospital for examination. After the examination, my mother, my older brother who was in the fourth grade, my younger brother who was then eleven months old, and I were sent to the sanatorium of the Minsk truck factory. We did not know where my other older siblings had been sent and my mother worried very much about them. Thanks to a kind doctor, we soon found out that they were at the labor holiday camp in Shumilino, Viteb district. My father went to work as a metal-worker in Petkovich village in the suburb of Minsk and lived in a dormitory there. When my older brother and sister wrote how difficult it was for them without their parents and that they were living under unsanitary conditions, my father went to see and brought them home with him.

However, with only one bed for the three of them, they were not able to live in the dormitory for long. Father found a flat and soon he called us all to live together as the sanatorium where we were staying was going to be closed down for repairs. Still we longed to go back home to Pogonnoe. But then we were told that our village was fenced off with barbed wire and nobody lived there any longer. The people of the village had all been relocated to many different places.

A few days later we moved again to Dzerzhinsk city. The flat had two rooms and was shared by two families, our family of nine and another family of four. We continued to go to school. Life was hard. Autumn came but there was no heating in our flat and we had to sleep on the floor without any blankets.

Nobody understood our situation, our sadness and pain. People approached us cautiously and adults as well as children looked at us as strangers.

In March 1987, we were offered a house in Petkovich village in Dzerzhinsk district. We were very pleased and happy to move to this beautiful big house and go to the Petkovich village school. Our joy did not last long as we children began to fall ill one by one, and soon we fell behind with our studies. We were all sent to a radiology medical clinic for examination. Since then we have been going for an examination every year. One day my father received bad results from a blood examination. Three months later he died. That was in June 1988.

Misfortunes and grief followed, one after another. In the same year my grandmother and aunt both died. It was an awful shock to us. Six of us were left with Mother. She, all by herself, had to bring us up. After all those sorrows, my mother too became subject to illness. Nevertheless, she tried to overcome all the grief and hardship, and wrapped us with love and affection. And we tried to understand her to ease her sufferings and tears.

Years have passed, and our life has changed a little. The pain and sorrow that filled our hearts has gradually abated.

“Grief of Chernobyl”, Isasiya Yana, 14 yr, Gomel region, Belarus, provided by Chernobyl Children’s Fund

We still live in the village of Petkovich. My sisters and my oldest brother have married. My next oldest brother serves in army, I am studying in vocational school, and my younger brother, Volodya, is in the third grade. Most of our fellow villagers now live in the Zhlobin district, and one of my brothers also now works there. I longed to visit him and meet people from our home village and so my mother and I visited Kirov village in the Zhlobin district. There I met a former classmate of mine. We used to be good friends, playing and studying together. After eight years, however, we did not recognize each other because we had grown and changed. It was as if we were meeting for the first time and I was both happy and upset. I was happy because I could meet my former classmates and a good friend, while I was annoyed and hurt because I had not seen them for so many years and could not go to school together because of the damned Chernobyl. I really did not want to leave them. But on the way home, I thought of my mother who is burdened with much sorrow and hardship, of many people's lives that were ruined and devastated by Chernobyl, and especially of innocent children who suffered and are still suffering without knowing what has taken away their happiness and health.

No matter how many years may pass, this tragedy will still leave indelible damage in our society, in the destiny of a great many people and in the memory of the whole world.

Remember, remember, everyone,
So long as we use atomic energy,
we cannot protect peace and harmony.
Let us clean the earth from this stain
and let nothing remain from nuclear drunkenness.

(Translated into English by HASEGAWA Kaoru)

<This manuscript was published in "Snowman was melted by our tears: Chernobyl for children" (1995) edited by Chernobyl Kyushu (http://www.cher9.to/) >

Activities of Chernobyl Children's Fund, Japan

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Chernobyl Children's Fund, Japan (CCFJ) was established in 1991 by HIROKAWA, Ryuichi, a photojournalist, senior advisor of CCFJ at present. Since its establishment CCFJ has been actively supporting people of the stricken areas: donating medicines and medical equipments, supporting the administration of sanatoriums and local relief organizations, giving financial aid for children's recuperation and the medical care of children having had thyroid gland operations.

Mother and child in the contaminated area. Photo by Hirokawa.

In 2006, twenty years after the accident, CCFJ has carried on some projects. We would like to impart information about these efforts, while referring, simultaneously, to activities of CCFJ in the past and future.

✧ Chernobyl Photo Exhibition in Belarus

As part of the 20-year campaign we organized and held a photo exhibition in Belarus in 2006. Chernobyl is becoming a mere disastrous past even in Belarus as well as in Japan. Or top government officials expect that the Chernobyl disaster should be over completely. How far can people in Belarus know about the accident when they are not given enough information? It is quite dubious. Hirokawa as a photojournalist had an ambition to make known the reality of Chernobyl by exhibiting his photos to doctors, specialists and all people concerned with hospitals.

In April 2006, we exhibited the photos at the venue of the International Conferences held in Minsk and Gomel. Having made an official proposal to the conference office for the exhibition, our negotiation with the office began around June 2005. After number of twists and turns, it was realized thanks to much help of the volunteers. The exhibition was held for five days in Minsk and two days in Gomel. Many people came to see it during the period: participants of the conference from and out of Belarus, members of citizen's organizations from various countries as well as ordinary citizens. It was especially impressive to see school students, led by their teachers, watching the photos so eagerly. People of Belarus were moved, above all, by the

Volunteer students at the photo exhibition in Minsk.

fact it is all Japanese who took such touching photos and managed the exhibition.

✧ **Fund-Raising Activities in Japan**

Chernobyl Aid Calendar

Since 1996 CCFJ has been making aid calendars. This project of Hirokawa's photo calendar was intended to make known the state of the stricken areas, and at the same time to raise the fund from its profit. The 2006 calendar was entitled '20- years old stigma of Chernobyl'. We carefully selected photos which Hirokawa took during his visits to the stricken areas for over many years and the calendar received a high reputation.

Aid Concerts

All the events we organize are entitled with the word 'aid' on top, because they are not mere events but always assigned to be fund raising campaigns. Every year on/around 26 April we organize aid concerts. This year we planned the concerts of Ukrainian singers Natasha and her sister Katya. We managed to hold nine concerts all over the country with the help of citizen's organizations. Many audience came to the performances of Natasha and Katya with the collaboration of a bayan player, enjoyed Ukrainian traditional music and had chances to think about Chernobyl and relief activities.

In 1996, to mark the 10th anniversary of the accident, we invited 'Chervona Kalina', a children's traditional music group, from Ukraine. They performed in various places in Japan. Natasha was a member of this group then. This music group was born from a music teacher's proposal in Pripyat, now a ruined city, who appealed to the children of evacuated families to form a music group, hoping the children would recover their health and hopes and expectations through their music activities. The group is still active, and children are practicing to sing and dance. In April 2006 they performed a stage in Kiev, together with previous members of the group who are already grown ups.

As for the 20th anniversary campaign, we also organized a summer concert. It was another fund raising concert with collaboration of Belarussian ballet and Ukrainian songs joined with a Japanese citizen's choir. All our activities are greatly supported by volunteers. Without their dedicated participation, we have not been able to continue to hold aid concerts for these years. They ask shops around the concert halls to put

Rehearsal of Chervona Kalina. Photo by Hirokawa.

on posters, distributing leaflets to make known the concerts and so on.
Money collected through concerts is all used for children of stricken areas, for the purchase of medicines and the payment for recuperation.

CCFJ News "Chernobyl Children"
We issue a quarterly newsletter, a circulation of about three thousand, giving financial reports to donors. The reports mention the state of donation, the uses of the money, conditions and states of children of stricken areas, events etc. All the operations for issuing newsletter: editing, printing, posting, are done by volunteers and the staffs of CCFJ office.
CCFJ news from 1997 can be also read in our homepage [http://www.co.jp/cherno/index.html]

Chernobyl Photo Exhibition and Children's Art Exhibition
'Photo exhibitions' and 'art exhibitions' play the biggest role in our publicity activity. The photos selected for the exhibition were taken by Hirokawa during his visits to stricken areas that count nearly fifty times. A sister organization, Supporting Group of HIROKAWA, Ryuichi Nonnuclear Peace Photo Exhibition possesses and manages about one hundred pieces of exhibition photos and pictures each.

In 1996, ten years after the accident, an Ukrainian organization appealed to children over the country for pictures about the Chernobyl accident. A selection of those children's pictures was sent to CCFJ as a gift. Another selection of children's pictures was sent from a Belarussian organization, too. We have chosen from these selections one hundred pictures to lend out for exhibitions. Later they were gathered into a book of children's pictures and poems 'Ikiteitai'('We want to live!' 1998, Edited by CCFJ, issued by Shogakukan) which has been read by many people.

Hurt by the atom from Chernobyl.
By Orga Sokolovskaya, 14yr.

These photos and pictures have been exhibited at various places such as CCFJ organized charity concert halls, citizen's organizations, city halls, schools, kindergartens, churches and temples.

✧ Relief Activities in Stricken Areas
In the beginning of its foundation CCFJ tried to do any support as much as possible. Eventually it turned to focus on the aid for children having had thyroid gland operations. Those children having had their thyroid removed by operation would no longer be able to produce thyroid hormone; consequently, they have to take hormone drugs throughout their lives. They also have to take vitamins and calcium tablets at the same time. Moreover, the children are facing the risk of breaking out of some other disease or spreading cancer to other organs. Some children must have many operations, and even more, many years after operations they might have to suffer from various symptoms: headache, heartache, exhaustion, etc. Therefore, it is necessary to support these children by providing them with medicines and occasions for

recuperation.

Support for the Children Having Had Thyroid Gland Operations and Support for Young Families

< Special recuperation >

CCFJ staffs with several volunteers have been visiting the stricken areas in summer to join the special summer recuperation at the sanatorium 'South'(Yuzhanka) in Ukraine and the sanatorium 'Hope 21'(Nadezda XXI vek) in Belarus. This special summer recuperation, having been held since 1996, is planned for the children having had thyroid operations, and CCFJ bears the total recuperation charge. However, as the situation has been changing, we now also accept elder age groups and children gone through other operations than thyroid. About fifty to eighty children in Ukraine and about seventy to one hundred fifty children in Belarus each year joined the recuperation.

< Foster parents system >

Originally it was the system to support the children gone through thyroid gland operations by sending fifty dollars per month to each child for the period of at least two years. This system, too, has been changed from supporting only 'the children having had thyroid operations' to 'the children of families in need and victims of Chernobyl'. A hundred children at present are supported by this system and two hundred children in total have had this aid.

< Scholarship system >

Sanatorium “Hope 21” in Belarus

Sanatorium “South” in Ukraine

This system of scholarship is addressed to the children having had thyroid operations. We send fifty dollars per month to each student, the same amount as foster children aid, to support until their graduation from colleges. Presently fifty students are receiving the scholarship and eighty students in total have been granted with this scholarship.

< Support for young families >

We have been supporting children who had thyroid gland operations mainly through above-mentioned three systems. Most children we have been supporting have now grown up and it is a time we should even consider the renaming of our organization. We have been discussing the matter these few years. Considering the present situation we have come to a conclusion that we should continue to support those grownups’ children having had thyroid operations who are now facing such problems as marriage and birth. We think continuous support is important for them. If one of the parents has thyroid disease and their baby has health problems, it is impossible for them to work fully as a healthy person even though they need money for medical treatments. CCFJ thus decided to support actively such young families with babies. At present we send fifty dollars per month to twenty four families.

In 2006, a couple who both had thyroid operations, experienced recuperations and received medicines with support of CCFJ have got married. It is happy news and we would like to watch over them fondly.

Supporting Local Relief Organizations and Management of Sanatoriums

We have been supporting the running expenses of the Sanatorium 'Hope 21' which has a function of school as well. It was built by Belarusian government in cooperation with a German citizen's organization. CCFJ has been collaborating to support the sanatorium from the beginning of its foundation. At first we mainly donated equipments needed for the sanatorium. Now we 100% support the special recuperation expenses and part of the rotational recuperation expenses of children who join in school class units from contaminated areas.

The amount of the backup money from Belarusian government and the donation from Germany are gradually decreasing. However, this is the best place for children for recuperation where they can also study and have safe food. Moreover, it is a beautiful place surrounded by forests and a lake and it can accommodate three hundred children at the same time.

In Ukraine we support the sanatorium 'South' located by the coast of the Black Sea. The sanatorium is managed by a support group in Kiev, 'the Help for Families of Chernobyl', and run only during summer. From the end of June to the end of August fifty children at a time recuperate in rotation. With cooperation of the local support group and hospitals CCFJ choose the children, attend the recuperation with them and proceed to send doctors to the sanatorium. The special recuperation for the children who had thyroid operations is also held there.

Since the summer 1996 we have been organizing a 'Japanese Week' at 'Hope 21'in Belarus and at 'South' in Ukraine during the special recuperation. Japanese volunteers join to carry out this special week. In 1998 eighteen volunteers flew from Japan to introduce Japanese culture and had enjoyable time with children.

CCFJ is helping the activities of local relief groups. We support the salary of the staffs, the office rents and communication expenses. We have sent them office equipments such as fax and personal computers. Through the groups we also send medicines to the children having had thyroid operations.

✧ Relief Activity in the Future

CCFJ have been supporting various local relief groups, some with big budget and others with small. We are also supporting some groups which were found during Hirokawa's visits to stricken areas to be in need of emergent help. Many relief groups and hospitals are receiving our help. All our supporting activities are always arranged through the local groups including personal support to foster children.

Unfortunately the amount of the donation has been on decline since 2001. Twenty years have passed from the Chernobyl accident. There are many people in the world suffering from wars, floods, earthquakes, tsunamis and other natural disasters. We must give priority to people who need the most urgent help. We will not forget to turn our eyes to the world and, at the same time, we will never turn our back to the victims of Chernobyl. We are going to continue our best efforts to support them.

(Translated into English by HASEGAWA Kaoru)

NANOHANA Project at Contaminated Area by Bio-remedy with Rapeseed Plant in Narodichi, Ukraine: A Challenge of Chernobyl-Chubu Association

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On April 13, 2007 we sowed seeds of NANOHANA (rapeseed) in the farmland at the Narodichi district. After the Chernobyl Accident, the land has been contaminated with radiation and has not been cultivated for 21 years. We imagined scenes that the rapeseeds were growing, bees were gathering around the flowers and the aroma of the yellow blossoms and sweet honey were everywhere. This was the beginning of our NANOHANA project to revive the Narodichi district.

Activities of our NGO, Chernobyl-Chubu Association

The local residents of Nagoya, Chubu District, Japan founded our organization, Chernobyl-Chubu Association to Help Chernobyl in April 1990. The aim of the organization was to provide relief for the victims of the Chernobyl accident. We sent a letter to democratic newspapers and magazine publishers in USSR (the then) inquiring about relief operation. Soon we received a reply from Ukrainian NGO, Fund Resettlement (the present Fund Chernobyl-Hostage), explaining that its members were journalists in Zhytomyr, Ukraine. In the letter, we offered our help to cooperate with them to help the victims.

In August 1990 our delegation brought relief goods to the disaster area. It was our first relief activity and relief goods as Japanese NGO for the victims of the Chernobyl accident. Since then we have

Rapeseed flower in Narodichi. June 2007

been continuing our relief activity for the victims in Zhytomyr, the area of Ukraine where the worst damage occurred.

At the beginning of our activities we had no idea how we could help them. We decided to send basic relief goods such as powder milk for babies, disposable syringes, and radiation instruments. We also sent a large quantity of Japanese calendars that were collected from Japanese citizens to raise funds so that the counterpart organization could purchase houses for the resettlement of victims to safe areas. Then we sent large amounts of medicine, incubators for newborn babies, as well as medical machinery requested by the local hospitals in Zhytomyr.

We have been also supporting several NGOs in Ukraine. One of them is the Fund Chernobyl-Fireman, an organization of liquidators who were engaged in operations coping with radioactivity just after the Chernobyl accident. They are helping incumbent firemen who are working in contaminated areas. Others are funds for disabled person due to liquidation works of the accident. The Milk- Campaign raises funds in order to send powdered milk to local hospitals. We believe that mental support is also a fruitful relief for suffering people, so we send cards every year at New Year and Ukrainian Christmas, which is called Card-Campaign.

Narodichi district, area of the highest contamination

Province Zhytomyr is located on the west side of Chernobyl NPP. 42 per cent of its land has been affected by radiation, 440,000 people suffered, and 9 out of 22 districts in the province were contaminated. The northern area of the province suffered especially high levels of radioactive contamination.

Based on the Ukrainian law, the level of contamination is classified into 4 categories: the 1st zone-prohibition entry zone (40 Ci/km^2 of Cesium-137 and above), the 2nd zone-obligatory resettled zone(15~40 Ci/km^2), the 3rd zone-optional resettled zone(5~15 Ci/km^2), and the 4th zone-radioactive control fortified zone (1~5 Ci/km^2). The Narodichi district is divided into two parts with contamination:

Contamination map of Narodichi

the northern area where the central town of Narodichi is located and the southern area where the Bazal village is located. Several other small villages surround the two areas. According to the map of radioactive contamination, we can see that the most severely contaminated area was the central part of the district where people cannot live.

Formerly there were 84 towns and villages in this district and now there are only 64. Before the accident there were 27,000 inhabitants in Narodichi district, but after the accident about half of them were resettled in non-contaminated areas. Currently, 10,300 people remain even though the circumstances of radioactive contamination. Almost all areas belong to the 2nd and the 3rd zone where people are better off resettling in other locations. Since the disintegration of USSR and the independence of Ukraine, the economic situation continues to be difficult. The population consists of 1,987 children, 4,330 pensioners and 2,374 working people, while 1,250 people are working outside the district.

Farming is the economic foundation of this district since before the accident. Today living conditions are difficult as the population suffer from health problems caused by radiation exposure and high unemployment. These conditions have led to a dysfunction of social structure. Inattention to these systemic problems has left people feeling of hopeless about their future.

People continue to suffer from internal radiation exposure due to the high level of radiative contamination in food sources. Subsistence farming produces most of the food that nourishes the Narodichi population. In addition to these cultivated food sources of crops, milk and domesticated animals, the Narodichi also gather wild mushrooms and berries from the woodlands surrounding the community. The high levels of radiation found in these local sources of food continue to cause internal radiation of the people. Substituting this local supply of food with cleaner food would entail a radical change in traditional eating habits and culture. As a part of its research efforts, the local government is measuring the level of radioactivity found in the foods that people occasionally bring into the regional health center laboratory.

According to the heads of local government and local hospital, researchers discovered high internal cesium readings by measuring the radiation levels in these patients' environments, including farmland, firewood, and foods, etc. In the last 10 years (1996 – 2006), morbidity of this district has risen by a factor

Ruined houses and goats

of two and the incidence of cancer is increasing 1.5 times faster than the decade before the accident. Tuberculosis also remains at a high level due to continued poverty. Anxiously, no children is healthy, they have some health problems.

Our assistance in Narodichi district includes repairing the hospital boiler, water infrastructure in a few villages and so forth. We have also sent medical equipment to hospitals. Despite our efforts, we could not help realizing that there remained a chain of problems: Radioactive contamination → Internal exposure → Radiation injury → Poverty→ Need of aid. Therefore, we thought of a novel approach that could cope with the principal roots of these problems.

The purpose of the project

The principal concept of this project is to use bio-remedial technology to reduce the number of patients in Narodichi suffering from radiation exposure. This technology depends on cultivating oilseed rape plants that can absorb cesium-137 and strontium-90 from the contaminated soil. The products of rapeseed and biomass are used for making bio-energy useful to agricultural and other purposes.

This project has been developed as a collaborative work of Chernobyl-Chubu Association with six Ukraine organizations: Narodichi Local Administration, The Local Assembly, National Agro-Ecological University in Zhytomyr, Narodichi Regional Specialized Station of the Land control in the Obligatory Resettling and Chernobyl Hostage Fund.

The first step to the land rehabilitation

Our job is to remove radioactive materials from the contaminated soil by growing rapeseeds. Rapeseed absorbs cesium-137 and strontium-90 from soil, but does not distinguish them from potassium (kalium) and calcium because of their similar nature. We can remove radiation gradually. The following explains the process of cleaning up the land.

First, we grow rapeseeds in Stare Sharne village located at the east end of Narodichi town, categorized 2nd zone (Cs-137 10~15 Ci/km^2). One of our members, a scientist of ecological-biology, collaborates with researchers at National Agro-Ecological University. During the first year of the project, we grew rapeseed dividing the field into 4 parcels according to the soil conditions and the amount of used fertilizer. We found that cesium-137 was accumulated mostly in seed; while strontium-90 was mostly in stalks. We are preparing a detailed report on this work.

Radioactivity concentration in different section

	Root	Stalk	Hull	Seed
Cs137	190	121.9	148.8	570.
Sr90	197	289	220.7	153

Mean on parcel of full fertilizer unit: Bq/kg

The work was shared as follows; the researchers of the Agro-Ecological University measured and analyzed radioactivity in the field and rapeseeds, and the agricultural technologists and workers of Narodichi Regional Specialized Station were responsible for growing rapeseed. They have to protect themselves by the guard manual to prevent exposure to radiation.

The second step: producing bio diesel fuel

After the first harvest, we planed to produce bio diesel fuel (BDF) from oil seeds. Our research data showed that the extracted oil was not contaminated with radioactivity, therefore, we can convert the oil to bio diesel fuel like the economic policy in Germany and other European countries. We believe the use of fuel will be very effective for the local residents in the region because it could be used for the agricultural tractors, cars, and public transportations like school buses.

In the meantime, a Japanese company, MSD Co., Ltd. in Tendo city, constructed a bio diesel fuel plant in Yamagata prefecture. The company showed a great interest in our project and decided to help us. However, we are worried about several problems. For example, it will be a long journey from Japan to the port Odessa, Ukraine, sending the BDF plants and other relief goods by ship might meet with any accident. Also, we hope to pass through the law and customs of Ukraine without taxation as a relief.

Producing Biogas

The other purpose is to produce biogas. After producing BDF, there will remain oil cake and botanical mass. These materials can be used to make biogas such as methane for fuel or electricity, which will be self-sufficient energy in the district. After producing biogas, we have to deal with the residue that contains a hint of radioactivity as radioactive waste. The experimental plant for that purpose was already designed in Japan by one of our members, a specialist of bio-energy. This is a starting stage before constructing a plant with our colleagues in Narodichi. Because very few biogas plants exist in Ukraine; there are a lot of problems we have to tackle with.

If the project progresses well, it will contribute to the regional economy, not only the agriculture section but also the industry in general. It will be obviously good also for the ecological problems such as global warming. We aim to make good use of bio energy for the victims to improve their lives. We should strive to develop our research and discuss with the local people how to use the new energy. We are going to continue this project for 5 years. Then after the project the equipments will be passed to the Ukrainian side.

Social and Economical Reconstruction and Development Programs of Narodichi District

The local economy in Narodichi district greatly depends on the subsidy from the central government. There is a program "Social and Economical Reconstruction and Development Program of Narodichi District" to improve the self-governing economic capabilities. The crucial problems are stable employment, improving and reconstructing the lives of the people.

It is proposed that the contaminated land should be divided into 3 areas; preservation area, forest –land, and farmland by radioactive contamination. In the farmland, new job opportunities will be created for growing rapeseed and producing BDF. Creating new economic opportunities is not our main purpose, but we are heading, as a result, toward the same direction of improving the peoples' lives.

The problems about social infrastructure are to repair of schools, kinder gardens, clinics, gas equipment in villages and so on. They are problems partly once we have supported. The head of administration said, "We are not unhappy and not poor in this district basically." They have some ideas and plans by themselves, but they are appealing for economic assistance for the resource. The stagnation of this district for these 21 years did not turn around, so it is difficult to do everything at a burst.

We hope that our project will become a model for the step to revival of Narodichi district. We believe it will be able to open up a hopeful vista in the future for the local administration as well as for the people.

With the same dream of revival in Narodichi district

So far we, Chernobyl-Chubu Association have supported the people in Narodichi by the ways as we thought better at the time. So our organization was occasionally requested for our activities like a

Farmer family and horse carriage

relief store. At the same time, we could not have a good grasp of the local situation nor the proper process of assistance. Frankly speaking, we experienced stresses with counterparts. Sometimes our relationship was not understandable each other. Recently, partly because of business recession, donation from Japanese citizen to our finance is decreasing. It brought us relying on official subsidies to maintain our activities. This tendency is not good both for our mentality and financial balance for retaining our identity and autonomy as a non-governmental organization.

In such a situation, the NANOHANA project is now attracting interests of many Japanese citizens who want to share the same dream of the project reviving Narodichi district as well as helping the people to find hope in their future.

The project is going on for 5 years, and it needs finance about 43,000 thousands yen. We could already collected half of it as donations from many citizens and as a subsidy from Japan Postal Office in 2007. But we have to continue raising donation, always appealing to people to share the dream of NANOHANA project. Instead of the current scenery with sparse people on the street and lots of ruined houses, wee wish to revive Narodichi district as it was in the previous days where people come and go lively and children are cheerfully smiling.

Episodes from My Experience in Belarus

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Prologue

The damage of Chernobyl is always described through the collection of different numerical data such as the number of migration, the number of children diagnosed with thyroid cancer and so forth. Systematically, it is essential to keep collecting, analyzing and reassessing these numbers. However, it is merely one side of the damage. It is necessary to try and look at Chernobyl with a more extensive perspective, otherwise we could never really understand the damages brought by the Chernobyl's disaster.

When I visited Belarus, I stayed at a health resort for Chernobyl's children in Minsk. Occasionally I met some people from foreign NGOs who visited the facility for few days for the purpose of investigations on the circumstances of these children. Afterwards and similar with all previous visitors they simply were satisfied with expressing the persisting sufferance of these children from the effect of radiation and then superficially they described the beauty of children's eyes. This behavior reminded me of my own experience when I first visited Belarus. I can say that our attitudes were exactly alike. I also had a preconception in my mind of what Chernobyl should look like and I only was able to see things from a unilateral perspective. Therefore I could not see or deal in depth with this disaster. I believe at that time it was a mere confirmation of my own expectations.

Since 2004 I have visited Belarus for three times and in total I have spent in Belarus more than half a year. Since I have a passion for photography, I decided to teach the children staying at the facility how to take pictures. I also visited contaminated areas, met the local people, performed some interviews and took many photos. Hereinafter are three selected episodes that I decided to share from my own experience while I was

A scene of a classroom. At a school in Vetka, Gomel province.

staying in Belarus 20 years following the Chernobyl accident.

Episode 1: Children

There were some impressive places while I visited schools in Belarus. One is a school in Vetka village in Gomel provinces where many villages of the neighborhood became deserted. A teacher said before I entered a classroom "In the next moment, you'll see what the nuclear accident brought to this region in 20 years."

It was a familiar scene that the electricity of the schoolhouse went off. But, I felt the classroom was the most cavernous in any schools I had seen. The number of children was extremely little compared with the size of the classroom. I embraced them with talking and looking into the eyes of the children who cannot hide their curiosity and shyness; while they touched their hair and shoulders and walked between the desks.

I noticed through touching each of the children that there were children, who have not set their viewpoints, who had language-disorder issues, or squirmed and kept moving their hands and foot. Such children came a lot to the institution where I stayed in. The most anxious thing for me was the boy who stared me with kind shy eyes, showing a wrinkly face like an old man because of his dry skin. The symptom of the boy was the same as a 17 years developmentally-disabled girl who is a member of family I stayed in. I had never seen a child who has such a face in Japan and Belarus either. I met two children of the same symptom in this small village.


A disabled boy at school (see txt).

These children live quietly without being viewed as a victim by the damage of the problem of Chernobyl. Once again, the number of these children is not included in the data telling Chernobyl. Nobody can delineate "where is the damage area" because the damage is too wide, too long and too deep.

After leaving the classroom, the teacher said, "All the things which you saw now are reality to be accepted and the product of that accident. Almost all children became weak and they can easily catch a cold. The developmental disorder stands out besides abnormal blood and thyroid, too. We were proud this village had breaded a lot of excellent children before. But recently, it was the finest record that I gave a student a silver medal* five years ago. We are very proud of our school which started from teaching at a church in 1888 and having a history of more than 100 years. However, now we have only 160 students, while there were about 800 students in 1985 to 1986. Because a lot of villagers migrated to Minsk and Gomel since the accident happened." Every word of hers resonated deeply with me.

※ In the schools of Belarus, a gold medal is presented when all subjects are best A, and a silver medal is given when a result is close to a gold medal.

I felt often in disaster-stricken villages that it's difficult for the people to find a piece of hope for the future, although it's easy to find a piece of happy memory from the past. Children should be hope to the future for a region of Belarus where various things are taken over from adults to children routinely, and continued. Though time goes by, adults are looking back on their past with bright eyes how the classrooms were full of students in happy harmonious.

Sad time is going by in disaster-stricken villages. A flow of time seems to have stopped from the day 20 years ago without looking the bright hope of a development of the village and continuation.

Episode 2: Story of Natalia

Natalia is a 55-years old woman, who living in Rechitsa, one of the contaminated areas. She felt unease with her body following the 1986 accident. She was always irritated and feeling dizzy all the time. After her visit to the village doctor and following his examination, the doctor informed her that everything looked normal because the size of her thyroid was constant. Then he prescribed for her a medicine that apparently was not working because she lost more than 20 kg in 15years and she did not feel any improvement in her health situation.

In 2001, she asked the village doctor if he could refer her to a more advanced and specialized hospital in Gomel. She felt that her symptoms were resulting from the exposure of the radiation of Chernobyl and therefore she wanted to hear another opinion and receive further examination. Accordingly she went to a well-equipped hospital in Gomel and she took more examinations. The doctor at this hospital has confirmed her fears and it turned out that her thyroid was damaged by the radiation. Fortunately after taking the medicine that was prescribed by the hospital doctor, her situation got much better.

During our conversation she said: “20 years have passed and still our medical capacity in the village is primitive. Their knowledge of the damage caused by radioactivity is still weak. I do feel nothing has changed since the occurrence of the disaster.”

After I explained for her how radiation could affect the human body, she was surprised. According to her, nobody raised their awareness and informed them about these influences. She was stunned by the fact that a foreigner who was visiting from Japan could explain many things that she could not learn from her everyday life in Belarus. She said that even the doctors did not feel the urge to communicate and clearly explain to her what was happening with her thyroid. She felt that even 15 years after the accident the village doctor could not locate the real problem and provide the sufficient medical care.

I do believe that there are many other misdiagnoses like Natalia’s case. Unfortunately these cases are not included in the Chernobyl’s conventional way of performing the research study. Actually we are unaware about their situation and therefore we do not include these victims in the investigation. Simply they are not counted. There could be many others who are still suffering from a misdiagnosis and were not as lucky as Natalia. Therefore we need to perform more investigation to locate these people and to provide them with the necessary assistance and awareness. It is our duty to help each other, and we need to do more.

With Natalia

Episode 3: Ignorance

Human body is continuously affected by radiation if people keep living in contaminated area. That is why, they are included as victims generally. However, during I stay in contaminated area, I found the fact that many people who live there are not realized that they themselves are one of victims.

In their understanding, they categorized only the people as victims who has physical symptom. They believed that huge amount of radiation affected them at the time, and it is the all result what was brought by Chernobyl I was very surprised because no one did not expect that the problem would come out gradually as symptom.

In some villages, people also told me that their village has been entered into the first stages of recovery program. That is, some of new construction would be started soon by government: water service, sewage system, and communal facilities etc. People dreamed the life with these stuff and they seemed to be so excited. In fact, many people said to me “After the accident, many people left our village. But in few years, the life in this village can be more convenient and then it brings the people back. It means, we can overcome the tragic accident”

Radiation is, by no means to be caught up by five senses, because it works without any smell, taste, colour and so on. On the other hand, improvement of living by facilities is easy to see. As a result, local people have “hope” for bright future with improvement stuff making their daily life better.

Local people still does not have correct information about radiation even 20 years after the accident. When their life will get more convenient and people back to their village as their wish, I am afraid it would make a situation producing new victims.

Conclusion :

For the past 20 years the approach in analyzing the damage of the Chernobyl disaster always depended on numerical data. This methodology is understandable, but it is important to recognize that it does not represent the whole picture of the disaster.

Now more than ever we are in need of innovative ideas to resolve problems that are still persisting and could not be detected through the conventional ways. I think it is necessary at first to try to look at the problem from a wider perspective and with more depth.

With my pupils and interpreter.

Citizens' Action in Response to Radiation from Chernobyl

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Over twenty years have passed since the nuclear accident at Chernobyl. As a result of this accident, the world, in particular Europe, moved towards a phase out of nuclear energy. In Japan too, the Chernobyl accident led many citizens to face up to the problems associated with nuclear power plants and a wide variety of campaigns sprang up around the country.

However, Japan continues to promote nuclear power. At the time of the accident, there were 32 nuclear power reactors in operation in Japan. There are now 55 reactors and the Rokkasho Reprocessing Plant is about to begin commercial operations.

Radiation from Chernobyl Reached Japan

The Chernobyl accident occurred on 26 April 1986. About a week later, radioactivity reached Japan, which is 8,000 kilometers away from Chernobyl. Rain which fell at the beginning of May was far more radioactively contaminated than expected. Quite high levels of radioactivity were recorded in leafy vegetables, fresh tea, milk from cows which ate contaminated grass, and so on.

The Ministry of Health and Welfare set a provisional standard of 370 Bq/kg (combined Cesium-134 and Cesium-137) for imported food and established an inspection system. Beginning with hazelnuts from Turkey, which in January 1987 recorded 520~980 Bq/kg, food from Europe exceeding the provisional standard kept turning up.

The Japanese government and the Ministry of Health and Welfare announced that "Japan's food is safe and imported food is being strictly controlled". Nevertheless, citizens' anxiety about contaminated food rose abruptly. Citizens' Nuclear Information Center (CNIC) received dozens of phone calls each day from people asking questions such as, "Which foods are contaminated?" or "What are the health effects?" In Japan, many people who discovered that the spaghetti that they ate and the tea that they drank was contaminated due to the Chernobyl accident faced up to the problems of nuclear energy for the first time. Until then, most city residents saw nuclear energy as someone else's problem, but in response to the Chernobyl accident many people began to take an interest in nuclear power as an issue of relevance to them personally.

CNIC's Activities

Through its newsletter, CNIC published the state of contamination throughout Europe and data obtained through measurements by Kyoto University Research Reactor Institute's Nuclear Safety Research Group and university researchers who supported a nuclear phase out. It also responded to inquiries from citizens and the media.

In April 1987 CNIC published a booklet, which covered the basics of nuclear power and radiation and also provided measurement data and information about the foods and regions for which precautions should be taken. The title of the booklet translates as “Fallout on the Dinner Table – Food Contamination from the Chernobyl Accident”. The impact of the booklet far exceeded expectations. In response to popular demand new information was provided in further publications: Part 2 (August 1987) and Part 3 (December 1988) of the same booklet and “Fallout on the Dinner Table” by Takagi Jinzaburo and Watanabe Mikiko (Kodansha Gendai Shinsho series, 1990).

In October 1987 a symposium on food contamination was held under the title “How to Protect the Dinner Table from Fallout”. In the same month, Nuke Info Tokyo, a bimonthly English newsletter from the Japanese movement, was launched with a view to actively disseminating information from Japan to the rest of the world. Through these initiatives, the range of CNIC’s activities and its support base expanded greatly.

Anti-Nuke Delivery Shop

Taking a hint from the Dutch grass roots “Science Shop”, Takagi Jinzaburo suggested starting an “Anti-Nuke Delivery Shop”. This started from the desire of non-expert citizens to communicate the problems of nuclear power in their own words.

It began in Tokyo in January 1987 with an “Anti-Nuke Delivery Shop” to train teachers with a accurate knowledge of nuclear power. After receiving 10 training lessons, in response to requests from citizens groups around Japan, the “shop keepers” began explaining the problems of nuclear power and communicating their concerns in their own words at study sessions around the country. Requests arrived for sessions ranging from study meetings for a few people to lectures for over a hundred people. A wide range of topics were covered, including food contamination, the structure of nuclear power plants and their dangers, accidents, energy and so on.

Training courses were also held in Hokkaido, Aomori, Chiba, Kanagawa, Nara and “Anti-Nuke Delivery Shops” sprang up throughout Japan.

Citizens’ Radiation Measurement in Japan

Citizens were very anxious, because Japan is very dependent on food imports. Incidents of shipments of hazelnuts, herbs and spices, mushrooms, etc which had to be returned continued to arise and there were also incidents of imported food processed in third countries that was contaminated with European ingredients.

Stimulated by activities in Europe, there were calls in Japan for an independent center to measure radioactivity. In September 1987 CNIC installed a radiation measurement device (Sodium Iodine Scintillation Counter) and began taking measurements where the demand was greatest, for example baby milk powder and spaghetti. In November, the device was moved from CNIC and an independent center (“Radioactively Contaminated Food Measurement Center” - Director Fujita Yuko) began taking orders for measurement. The Center had a management committee comprising staff involved in taking measurements, citizens, experts, consumers groups and cooperatives.

At the same time, several other organizations independently installed radioactivity measuring equipment and began carrying out measurements for citizens. In Aomori, members of the students’ group “Environmental Medicine Research Group” at Hirosaki University Graduate School began taking measurements. “Hamamatsu Radioactively Contaminated Food Measurement Center” and the

Tokyo-based Tampopo House radioactive contamination measurement team began in the middle of December 1988, while in Osaka the "Committee to Measure Radioactivity in Food" began in April 1989 in the Environmental Monitoring Research Center.

Also, there was an active movement all over Japan to encourage local governments to install not thrown away. It was turned into animal feed, so it will return as contaminated cows milk and meat. It will also make its way to third world countries, so a strict international information and monitoring network is needed to prevent this.

What is the Value of Continued Measurement?

As time went by the trend was for measurements not to detect any radioactivity. Citizens became less interested as contamination of imported food was brought under control and requests for measurement became fewer. We faced the problem of how to maintain testing activity. There was a fundamental debate about the purpose of continuing measurements. However, we learnt that it is strict monitoring activities by citizens that brings pressure to bear on the government and companies.

Chernobyl showed us that one accident at a single nuclear power plant can spread radioactivity throughout the whole world and leave lasting effects. Some people said that they felt despair when they thought of the problems for the next generation of children facing contamination of food and of the environment. On the other hand, there were also many people who found hope in the friendships formed through their activism.

Measurement equipment is now approaching its use by date. In some places lack of funds to replace equipment and the failure of local governments to provide continuing funding have forced programs to close. Many groups are involved in numerous local issues besides measurement. Along with younger people, they continue their steady efforts, screening films and taking up themes closely connected to daily life such as sustainable energy, nuclear disaster prevention, etc..

The Criminality of Japan's Radiation Effects Researchers

Five years after the accident, in May 1991, the IAEA's International Advisory Committee concluded, "There were no disorders directly attributable to radiation exposure, but the survey did find many health disorders. The accident affected people psychologically, and also worsened the socioeconomic situation (the report suggests that these were related to the health disorders)." It also dismissed the increase in child thyroid cancer which had begun to appear as follows: "There are no definite pathological records of increases in thyroid cancers caused by radiation,…."

We at CNIC promptly criticized the report in a special 15 June 1991 edition of our Japanese newsletter and in a special edition English newsletter of our entitled 'Erasure of the Chernobyl Accident is Unforgivable, A Critique of the IAEA/ IAC (International Advisory Committee) "Assessment of Radiological Consequences and Evaluation of Measures for the Chernobyl Accident "(May 21, 1991) ' .

We also sent our protest overseas through our English newsletter, Nuke Info Tokyo. An article in the July/August 1991 (No. 24) reported on a demand by anti-nuclear groups' for the cancellation of an IAEA seminar held in Tokyo in relation to the report.

The chairperson of this Committee was Shigematsu Itsuzo, who at the time was head of the Radiation Effects Research Foundation in Hiroshima. It was criminal that the head of an organization tasked with researching the effects of radiation exposure at Hiroshima and Nagasaki played such a role. Before pursuing the question of whether the illnesses suffered by victims of the accident were the result of radiation, the first priority should have been to clarify what type of illnesses there were and to provide relief. Based on the precautionary principle of protecting people's health, it was necessary to respond promptly to suspected causes.

At the center of those strongly refuting the claims of a sudden increase in thyroid cancer were Shigematsu Itsuzo and researchers from the Radiation Effects Research Foundation. They should admit that the 1991 report got it wrong, but to this day we have heard no statement from them admitting their mistake.

To say there is no effect and ignore the issue, just because it has not been scientifically proven, is not a scientific response. They should carefully examine the data to find the trend in the incidence of cancer and the rate of death from cancer over the period since exposure, then extend that to estimate the incidence of cancer and the number of deaths from cancer into the future.

Epidemiological studies of victims of the nuclear bombs in Hiroshima and Nagasaki are still continuing 60 years after the bombs were dropped and as time goes by valuable new information keeps emerging. In regard to solid cancer, the latest Life Span Study (Report 13) report (Preston et al. *Radiation Research*, 2003), "The excess solid cancer risks appear to be linear in dose even for doses in the 0 to 150 mSv ."

Japanese researchers into the effects of radiation should thoroughly come to terms with this fact and spread the message to the world. They should also strive to clarify the effects of long term exposure to low doses of radiation, including the effects of internal exposure.

The American National Academy of Sciences' BEIR-VII report (Biological Effects of Ionizing Radiation VII, National Research Council of the National Academies, 2005) concludes, "current scientific evidence is consistent with the hypothesis that there is a linear dose-response relationship between exposure to ionizing radiation and the development of radiation-induced solid cancers in humans."

There are new moves in Europe. In regard to the assessment of the effects of radiation from the Chernobyl accident and for people living near nuclear facilities, the European Committee on Radiation Risk (2003 Recommendations of the ECRR, Green Audit 2003)) is demanding that, instead of depending on a risk model based on exposure data from Hiroshima and Nagasaki, organizations which promote nuclear energy such as IAEA and ICRP should conduct Europe-wide epidemiological research employing a new scientific basis.

Most of Japan's radiation effects researchers are ignoring these moves. They still refuse to engage in deep debate. They continue to dismiss the effects of low radiation doses to Chernobyl victims, victims of the JCO criticality accident, people living in the vicinity of reprocessing and nuclear power plants, and nuclear workers saying, "There were no effects on the hibakusha of Hiroshima and Nagasaki at these levels of exposure, besides which the dose is unclear."

We must engrave these problems in our hearts and continue to monitor and critique the situation.

From Archives of VUChK-GPU-NKVD-KGB
Chernobyl Tragedy in Documents and Materials
(Summary)

Volodymyr Tykhyy

General overview of the book

The book **"From archives of VUChK-GPU-NKVD-KGB. Chernobyl tragedy in documents and materials"** (*Z arhiviv VUCHK-GPU-NKVD-KGB. Chornobylska tragedia v dokumentakh ta materialakh,* №1(16) 2001) was published by the Security Service of Ukraine (SSU) in 2001. SSU is a natural continuation of the Soviet *KGB* (Committee of the State Security of the USSR), so SSU inherited KGB archives and disclosed some documents when the appropriate legislation was passed by the Parliament of Ukraine beginning in 1994 with the Law "On State Secrets". It is essential to note that on 10 December 2005 the book was also posted on the web-site of the SSU (http://www.sbu.gov.ua/sbu/control/uk/publish/article?art_id=39296&cat_id=46616).

KGB is a unique source of information, because it worked "across the lines": it was subordinated neither to nuclear industry nor to army generals; it supervised activities of industry, government and municipal authorities, construction companies and cooperative shops alike. KGB officers collected information from all sources they deemed reliable, they often were able to cross-check it and then to present to higher levels of hierarchy - in KGB, Communist Party, Government of Ukrainian Soviet Socialist Republic. So, this information contained quite reliable facts, which were formulated without flatter - moreover, it was either "secret" or "top secret". Unfortunately, this does not mean that their reports were given any special attention - the system had its own inertia, and KGB was an integral part of the system. This is especially well illustrated by the case of Chernobyl nuclear accident of 9 September 1982, which is well represented in the published documents.

In fact, the book is an encyclopedia of everyday technical, professional, social life of Chernobyl NPP before and after the accident of 1986, and that is why it is difficult to make a summary of it. The book perhaps deserves a careful translation with necessary comments, to serve as a source of very important lessons. It should be remembered, however, that the selection of documents was made by KGB itself and thus they might not represent a whole picture.

The book (400 pages with 17 photographs) consists of Introduction, Preface, 121 documents (mainly information communications) of different KGB units and 5 memoirs of participants of the liquidation of Chernobyl catastrophe. Of 121 published documents, 20 are of pre-disaster period, and 101 cover period from 26 April 1986 - 6 December 1988. Original KGB documents are in Russian, while other materials and comments in the book are in Ukrainian.

This summary is based on internet version of the book. For convenience, documents were grouped according to their dates and main topics. Two most representative documents were translated to give a reader first-hand feeling of wording and style.

Summary of Introduction and Preface

Chernobyl Nuclear Power Plant named after V.I.Lenin, as an industrial object of strategic importance, was under the permanent supervision of KGB organs from the first day of its construction. In the process of regular investigations by the KGB personnel in the pre-disaster period numerous facts were revealed of bad construction work quality, supply of faulty equipment, violation of technical rules of operation, violation of fire and radiation protection rules. Reports on these cases were presented to the management of the Chernobyl NPP and highest party (Communist Party - *VT*) and government authorities of the Ukrainian SSR and former USSR.

Already at 2:30 am on 26 April 1986, after the message about explosion and subsequent fire on Chernobyl NPP was received, investigators from KGB of Ukrainian SSR were dispatched to the city of Pripiat and Chernobyl NPP. On the same day the accident on the NPP was reported to the high command of KGB of USSR.

During first five years after the accident 1,500 officers of KGB of Ukrainian SSR and hundreds of KGB officers from other republics of USSR participated in investigation of causes and the work on liquidation of the consequences of the disaster.

Specific feature of the documents of the soviet secret services related to the Chernobyl catastrophe is that they present a complex picture, unlike materials of other government agencies that are concentrated on narrow special issues. This allows for producing a rather full and systematic analysis of all spectrum of Chernobyl problems.

In preparation of this special edition (of Archives of KGB - *VT*), the most characteristic and informational deep documents were selected. They provide integral picture not only about pre-conditions, circumstances and consequences of the accident, but also about problems and mistakes during localization and liquidation of the consequences of the accident.

Documents are presented in chronological order covering the period from 1971 to 1988.

Summary of documents: Pre-disaster period

Technical characteristics and faults of the design of RBMK reactor

In September 1971, when the decision to build the Chernobyl NPP with two units was made, KGB prepared information memo on the design of the plant and reactors (Document 1). Information was based on materials of the Ministry of Energy of Ukraine, however, it is not clear to whom this memo was submitted.

Apart from providing general technical data, the document tried to analyze the safety issues of reactors, and mentioned several drawbacks and weak points (like accidents with break of main pipelines).

Concluding paragraphs of the document are very important because they show that Ukrainian authorities did not have necessary information and capacity to control the situation:

> "This is a brief summary (based on the experience of use of Soviet reactors and found in open published materials) of the radiation safety issues of NPP. More detailed information, including safety regulations, organization of operation and requirements to the personnel is in the disposition of *Glavatomenergo* of the Ministry of Energy of the USSR and other specialized organizations. The

> Ministry of Energy of Ukraine does not have other information and does not have experience of operation of nuclear power plants".

After four years of operation, insufficient reliability of control equipment became clear. The summary was presented by Kyiv oblast KGB Department to KGB of Ukraine in the memo of 16 October 1981 (Document 8).

> "During the period of operation 1977-1981 there were 29 emergency shut downs, for 8 of them personnel was responsible, and other were due to technical reasons... Investigation shows that control equipment does not meet the requirements for reliability due at the nuclear power plant... The issue was several times brought to the attention of "*Soyuzatomenergo"* and design institute "*Hydroproekt"*, but it is not resolved yet... In the system of control rods logical schemes, as well as relay and contactors are of low reliability, and this caused emergency shutdowns in 1979 and 1981".

In a special information of October 1984 (Document 17, entitled "Main engineering and technical faults of Chernobyl NPP units, resulting from design"), a summary of problems was reported to the KGB of Ukrainian SSR.

> "In the process of counterintelligence measures... we conducted analysis of the reliability of the work of Chernobyl NPP... The first and second units are less reliable in terms of environmental safety, because in case of the break of main pipelines with diameter more than 300 mm, the systems of emergency shutdown and safety will not secure localization of cooler, and this will lead to radioactive contamination of the area...
>
> The system of cooling of main circulation pumps is insufficient (lower than norms by approximately 39 %)... The designer (*Hydroproekt* Institute) was notified on this after the analysis of experience with unit 1, but even on units 5 and 6 that are now under construction, these comments are not taken into account...
>
> Because these and similar problems can lead to emergency situations, we officially notified the management of the Chernobyl NPP in August, with a recommendation to tackle these faults. Until now, necessary measures have not been implemented".

Problems encountered during construction period of Chernobyl NPP

There were numerous reports by different KGB departments on unsatisfactory quality of design of Chernobyl NPP units, as well as the quality of construction works. Altogether, 7 documents from 1976 - 1986 are published. These reports were submitted to higher levels of KGB and to the Ukrainian State and Party authorities. Often the reported faults were howling.

KGB reported of the bad quality of welding on main pipelines, which anyway were accepted and installed (Document 2, 1976), of faulty equipment supplied by numerous factories from all over the USSR. There were permanent violations of technical rules during concrete works, roofing, welding. On 17 January 1979, a special memo on violations during construction works was submitted to the Central Committee of the Communist Party of Ukraine (Document 3). Not only Soviet, but also other suppliers shipped faulty equipment, like Yugoslav companies which supplied pipes and steam separators (Document 15, 9 January 1984).

Some violation demonstrated negligence of technical requirements: during construction of unit 5, instead of small rock fraction 5-20 mm, a fraction 20-40 mm was used, and this did not allow filling of reinforcement of the floor/ceiling (which had to carry 1000 tons of equipment - steam separators). The problem was uncovered in time, but hundreds of square meters of concrete had to be replaced (Document 20, 26 February 1986).

Nuclear accident of 9 September 1982 at reactor # 1

On 10 September 1982, a report of KGB Department in Kyiv and Kyiv oblast was submitted to KGB of Ukraine and USSR about the nuclear accident at reactor # 1 of Chernobyl NPP: rupture of one of 1640 technological channels. KGB reported that there was no contamination of the plant and that estimated 5 days are needed for repair (Document 9).

In the next document more full and severe picture of the accident appears. Already on 13 September (Document 10) detailed technical information was presented: channel's stainless steel pipe, diameter 88 mm with walls 4 mm broke up at the depth 9.6 m from the top, and graphite blocks near the rupture were washed out by water and steam, to the diameter of 170 mm and surface area 660-670 mm. Fuel was washed into this hole. Estimated time needed for repair - 10 days.

> "According to the statement of Director of NPP Briukhanov and Chief Engineer Akinfiev, zirconium casing of the fuel was not destroyed, so there was no radioactive contamination of technological chambers".

High levels of radioactive contamination inside the reactor building and around it were reported 14 September (Document 11, 12). It was also reported that fuel was sucked into the washed out hole during repair works. Gamma-level in some chambers of gas contour and drainage systems was 1000 microroentgens/sec. Radioactive aerosols were also released through ventilation stack, and gamma-levels on the surface near the station in some point were 0.01-0.02 microrem/sec. "Administration of the NPP started decontamination measures (concrete and asphalt surfaces are covered with soil, leaves etc.)"

The full picture of the consequences of the accident was reported to the Head of the KGB of Ukraine on 30 October 1982 (Documents 13), and subsequently to the First Secretary of the Communist Party of Ukraine. These reports were based on the findings of commissions, organized by the nuclear industry (including specialists from Chernobyl and Pripiat, as well as from Moscow institutes) and of Academy of Science of Ukrainian SSR, created by the decision of the Minister of Energy of UkrSSR V.Skliarov.

Commission of nuclear industry investigated radioactive contamination near the plant itself and in sanitary protection zone of NPP (3 km radius) and observed zone (35 km radius). The distance of pollution reached 5 km from the stack of the plant in S-SW direction and 14 km in the N-NE direction. As of 10 September, levels of radiation in the sanitary-protection zone varied between 0-03 microrem/sec. By 25 October, the levels of radiation dropped by 1.8 times. Various fission nuclides were detected in samples, and iodine was detected in the air at the levels of 10-14 Ci/l.

The conclusion of the Commission states, that

> "the radioactivity of air and the density of radioactive depositions as of 25 October does not differ from parameters, characteristic for the normal regime of exploitation of NPP (during repair works on unit 1 and operation of two other units at full capacity). Radionuclides were not detected in discharge water and in cooling lagoon".

On contaminated territory in S-SW direction "hot" particles were detected, with activity between 5*10-8 and 2*10-7 Ci. Uranium was identified in these particles.

The Commission concluded that there is no need for implementation of measures, envisaged by the "Temporary guidelines... for protection of population in case of nuclear accidents" approved 18.12.80.

The group of scientists from the laboratory of biophysics of the Institute of Nuclear Research of the Academy of Science of UkrSSR came to somewhat different conclusions. They measured the beta-activities of soil samples, which was between 2.6*10-9 to 2.23*10-7. Fission radionuclides, as well as products of activation were detected in these same samples. Near Chistogalovka village , located at 5 km from NPP in S-SW direction hot particles were registered, with activities up to 10-7 Ci, which is hundred of times higher than permissible levels. Radioactivity caused by the accident and the following desactivation was registered in the cooling lagoon and bottom sediments. In the opinion of this commission, hot particles could lead to serious, even lethal consequences. This requires further analysis and decisions regarding liquidation of "hot" particles, and this decision depends on the 3rd Main Directorate of the Ministry of Health of the USSR.

Members of the Commission reported that their findings would be presented through the Minister of Energy and the President of the Academy to the Central Committee of CP of Ukraine and the Council of Ministers of Ukraine.

Similar report was indeed submitted to the First Secretary of the Central Committee of CP Ukraine V.Scherbytsky on 5 November 1982 as "top secret", "personally". It was added that "situation at the power plant and the vicinity is normal, no facts of panic and rumors".

Another report of October 1984 (Document 17) provided still more details:

> "The reason for disaster was an overheating of the channel due to insufficient flow of cooling water. During the accident a large volume of water (more than 200 tons) permeated the graphite core of the reactor".

Summary of documents: Post-disaster period

Catastrophe of 26 April 1986 and it's immediate consequences

First report about the explosion was filed already on 26 April (Document 21). Other reports describe radiological situation around the stricken power plant, in nearby towns and villages, inform about evacuation measures:

Several reports mention radioactive contamination of food products, recommendations for handling contaminated food and other practical problems. In Kyiv, 4 samples of bread baked on two bakeries (#2 and #7) were contaminated to the levels of 5.9*10-8 Ci/kg - 8.8*10-8 Ci/kg. This happened apparently due to use of whey in leaven (Document 39, 28 May 1986). Document 30 reports about the absence of reliable dosimentric devices in civil defense system, and ignorance of population on radiation protection issues.

During all period represented in the book, reports provide detailed information on the levels of radiation, like

> "Situation with radioactivity levels remains stable. The level of radiation at the site of NPP is 0.5-1000 roentgen/hour, in the zone of lean-up 1.4-200 roentgen/hour, in the city of Prypiat 0.2 roentgen/hour, in Chernobyl 6 miliroentgen/hour, at the boundary of the 30-km zone 8 miliroentgen/hour" (Document 34, 15 May 1986).

In later reports the data on levels of radiation become more detailed - obviously because the number and accuracy of measurements improved.

Reports on liquidation measures and encountered problems

Already on 5 May emergency works for protection of river Pripiat from contamination were started - construction of 6 dikes. 120,000 sq.m of film and liquid glass for desactivation were received. 100 miners started digging the tunnel under the damaged reactor (Document 28).

Many documents provide evidence of the bad organization of work in the exclusion zone. Stations of sanitary treatment of wastes and contaminated clothes were not operational, personnel not trained, wastewater discharged in surface water without treatment (Document 32, 12 May 1986). Workers drafted for work in the zone were not informed about radiation levels, terms and conditions of their work, transportation and living conditions were bad. This led to complaints from the workers (Document 33, 13 May 1986).

Tens of reports mention cases of negligent and irresponsible behavior of workers. "Miners and military men do not use individual protection measures, they receive exposure that is not caused by work need, they rest near contaminated machinery and inside of it, do not keep up to hygiene rules. This leads to early overexposure" (Document 37, 22 May 1986). But there were also problems with supply: "... plutonium concentrations exceed the permissible level by 1000 times. This requires use of gas masks, but until now responsible ministries have not provided their personnel with necessary protective equipment" (Document 41, 1 June 1986).

> "For liquidation of the consequences of the Chernobyl NPP disaster, by the order of the Minister of Defense of the USSR 94 military units were mobilized and stationed in the area... These include regular military, civil defense, chemical defense, medical, engineering units, land-forces and aviation, with total number of 32,329 men" (Document 46, June 1986).

These troops and servicemen not always were used efficiently. Many were drafted without explanations and consent, were not told they will serve in Chernobyl zone. Some appeared to be unfit for the work, some were over 45 years old, some were ill. Hundreds had to be sent back home. Many received doses higher than permissible. There were cases of short hunger strikes (Document 51, 4 July 1986 and other documents).

Some decisions by the State Commission were highly controversial, like the decision to restart unit 3 of the NPP. Many specialists express their objections (see translated Document 75, 1 February 1987 in the Annex). By the end of May 1987, desactivation of the Unit 3 was not completed, e.g. "radiation levels at where cables need to be replaced are quite high - up to 1 Roentgen/hour, on the other hand, it is necessary to remove by hacking about 1000 m3 of contaminated concrete..." (Document 83, 4 June 1987).

KGB was also concerned with technical problems of the "Shelter". Many details were unclear, e.g. specialists of the Academy of Science of Ukraine estimated that 6 % of fuel were released from the damaged reactor, while specialists of the *Minsredmash* opined for release of 30 to 50 %. This made decisions difficult (Document 108, 2 April 1988). The problem of radioactive waste remained serious as well:

> " - there are two operational *PZRO* (repositories for radioactive wastes):
> 1. "*Buriakovka"* for wastes up to 5 Roentgen/hour. Design capacity 450,000 m3. There are altogether 30 trenches, of which 14 filled.
> 2. "*Podlesnyi"* - for radioactive wastes 5-250 Roentgen/hour. Altogether 8 vaults 50x28x8 meters... Vaults 1 and 2 are partially filled.

- there are 8 temporary repositories, where radioactive wastes were stored during first months after the accident;
- more that 200 sites where various buildings, materials, contaminated soil etc. are buried.

Some specialists express opinion that temporary repositories are below critic from the point of view of construction norms. Clay lining on some of these storages can fail to work ling before the guaranteed term, and that will lead to filtration of radioactively contaminated water into natural aquifers" (Document 120, 9 November 1988)".

Technical problems of nuclear industry in Ukraine

Chernobyl nuclear accident highlighted many problems of insufficient safety of nuclear industry. KGB paid a lot of attention to this - tens of published documents deal with these issues.

Investigation of preparedness for nuclear accidents revealed big gaps. At Zaporizha NPP:

"...the stock of iodine medicines was sufficient only for personnel of NPP (for two days instead of 10, as required), and there was no such stock of medicines for NPP construction workers, citizens of Energodar city and the 30 km zone. As of beginning of July, the stock of iodine preparations for population of Zaporizha oblast was about 20 % of needs? and in Mykolaiv oblast - about 22 %. The procedure of delivering these preparations to users is not in place." (Document 56, 27 July 1986).

Confinements of some reactor units at Rivne NPP and South Ukrainian NPP were built and are used despite of significant faults. "At Rivne 3 uptightness is 2.44 % while design requirement is 0.1 %. Similar problems at South-Ukrainian 1 and 2. This may lead to serious consequences in emergency situation. The reason is in the absence of unified requirements to designing, construction and operation of such systems."

Control equipment was often uncertified and unoperational:

"At South Ukrainian NPP, of 811 control devices, including equipment for radiation measurements, tested by organs of State Standards Committee of the USSR, 469 appeared to be unusable" (Document 72, December 1986).

KGB informed the Central Committee of CP of Ukraine that there are numerous problems with water use for nuclear industry needs. Problem existed on all NPPs. In Chernobyl, very high filtration of water from cooling lagoon due to the absence of special antifiltration measures. In spite of the decision of the Council of Ministers of Ukraine of 1982, similar problem exists at Zaporizka NPP. At Rivne NPP and South-Ukrainian NPP discharges of water from plants lead and will lead to river contamination (Document 62, August 1986).

Spent fuel storage was a persistent problem:

"At South-Ukrainian NPP, the Ministry of Energy of the USSR did not reconstruct the basin for spent fuel assemblies, so instead of 162 (design capacity) currently 171 are stored at Unit 1. In 1987, 73 assemblies will have to be unloaded, and it is not possible to store them without violations. Similar situation exists at Unit 2" (Document 71, 14 November 1986).

"At Chernobyl NPP, radiation situation in central halls of Units 1 and 2 is very unfavorable. Gamma-radiation level exceeds permissible level by 10-15 times, and it leads to additional exposure of personnel. The reason is storing of unacceptable high numbers of spent fuel assemblies in basins... At unit 1, there are 2803, while the design capacity is 1728, at Unit 2 - 2414 and 1568 respectively" (Document 87, 29 June 1987).

There were continuos problems with reloading of fuel. At Chernobyl NPP, reloading of technological channel 50-21 failed, because the fuel assembly could not be pulled out neither at regular pull 500 kg, nor

3000 and 4000 kg (maximum permitted). Later it was reported that personnel applied 5000 kg without any permission. Reload was delayed by 10 days until the scheduled shutdown of the unit. Similar problems occurred on 26 and 30 April at unit 1. (Document 84, 7 June 1987). On 17 June 1988, there appeared problem with hermetization of channel 57-37 after reloading (Document 113, 9 July 1988)

Factors that influence the safety of NPP operation were summed up in the report of 16 July 1987, which was prepared with participation of KGB department in several oblasts:

> "During the current year, there were 66 emergency shutdowns at NPPs, located in Ukrainian SSR. Of them 41 at Rivne NPP, 19 at Zaporizha NPP, 5 at South Ukrainian NPP and 1 at Chernobyl NPP.
> ... main causes of emergency shutdowns are:
> - faults of design and construction works - 37%;
> - faulty equipment - 43%);
> - unskilled actions of NPP personnel -20%.
>
> There exist substantial design defects in the design of VVER-1000 (approved by the Order of the Ministry of Energy of the USSR on 30 December 1985). Faulty decisions and mistakes continue to be copied in documentation for construction, assembling and start-up works, as well as designs for suppliers of equipment. These designs are provided to the NPPs of Ukraine, as well as abroad (to Bulgaria, Hungary, GDR and Czechoslovakia)". (Document 88, 16 July 1987)

Secrecy and foreign visitors

Secrecy was an essential feature of all Soviet nuclear program, and Chernobyl disaster was no difference. All ministries and other government agencies working in the 30-km zone were obliged to keep secrecy. "Upon the directive of the Head of the Government Commission, requirements regarding secrecy were presented to the heads of organizations by the representative of the KGB of USSR". When it became known that transmission of radiometric data by radio would be organized, KGB was on alert: "Some specialist admit that digital code might be deciphered, and this would make possible leakage of information to an enemy. Department 6 of the KGB of Ukrainian SSR supervises these works". (Document 57, 10 August 1986).

Violations of secrecy were apparently quite common. "In the 30-km zone, groups of specialists from over 70 research and design institutes work on permanent or temporary basis. Most of them violate rules of work with secret documents prescribed by the Instruction 0166-72." (Document 85, 22 June 1987).

The secrecy hindered the work on liquidation of the consequences. The Minister of Water Resources of Ukraine V.N.Tkach complained that to protect water resources, detailed information on radioactive contamination of territory is needed. However, it is possible to obtain such a map only in the State Committee of Hydrometeorology of the USSR and *Minsredmash* of USSR. The Minister raised this issue several times after 10 May at the meetings of different commissions, but there was no positive decision so far. (Document 42, 3 June 1986).

Since autumn of 1986, there are numerous reports on visits of foreign journalists, scientists, other delegations to the 30-km zone (Documents 73, 77, 80, 81, 96, 98, 110). Usually the conclusion was "there were no hostile intentions from foreigners; information passed to their agencies was objective". Sometimes, however, incidents did occur: journalist of NHK telecompany Yamayghi Toshihiro tried to collect samples near Chernobyl NPP and used dosimeter with automatic recording of data. These attempts were, of course, suppressed. (Document 96, 6 October 1987). In November 1987 KGB reported:

"We obtained direct evidence of intelligence efforts by foreigners who visited Pripiat and Chernobyl in 1986-1987. There were attempts to acquire secret data on liquidation of the consequences of the disaster, on technical condition of reactors, radiation situation in the zone, new methods of desactivation of territory, industrial buildings and equipment, chemicals that are used for these purpose and so on. Attempts to collect and export samples of soil, water and biomass were disclosed and suppressed" (Document 98, 14 November 1987).

Health, social and other impacts

As it was already mentioned, KGB reported about cases when patients evacuated from the 30-km zone and NPP workers were delivered to hospitals in Kyiv or Moscow. Later there appeared controversy between Ukrainian and Moscow doctors. KGB reported, that according to obtained information, Ukrainian scientists headed by Academician K.S.Ternov achieved good results when treating patients with their methods. Professor Gail (USA) noted successful treatment in Kyiv clinics. But use of these methods was banned by Academician L.N.Ilyin and Major-General E.E.Gogin without explanations, and the state of patients worsened.

"One of Prof. Kindzelsky's patients, firefighter Miagkov visited in the clinic of the Institute of Biophysicss of the Ministry of Health of the USSR his colleagues, who participated with him in combating the fire at Chernobyl NPP. He found them in bad condition (loss of hair, "parchment" skin, hemorrhages and necrosis of tissues at burns etc.) They told Miagkov, that they receive practically no treatment, doctors only observe them". (Document 63, August 1986).

High committed doses were serious problem for works at Chernobyl NPP: "Effectiveness of organization of work is seriously deteriorated by the fact that of 124 senior specialist more than a half already received doses 25 rem and more. If these specialists are replaced, the stability of management can be seriously deteriorated". On the other hand, some workers try to hide committed zones because they can lose their jobs in the zone. In such cases it is very difficult to control radiation doses of personnel. There are 4925 employees at the NPP, 91.8 % of needed engineers and specialists, 88 % of needed workers. (Document 74, 20 January 1987).

"...analysis of individual doses of those who are controlled by the Dosimentry Directorate of "Kombinat" enterprise shows the following results as of 15 August 1987:

Subdivision	Period	Distribution of personnel according to their doses (rem)					
		0-5	5-10	10-15	15-20	20-25	25
All organisations, except ChNPP	1986	26471	1494	522	285	161	196
	1987	22706	154	41	21	12	27
Personnel of ChNPP	1986	3052	-	304	175	147	53
	1987	4150	-	14	7	5	3
Total	1986	31017	-	826	460	258	416
	1987	27010	-	55	28	17	30

According to official data of the Dosimetry Directorate, necessary investigations on the cases of excess exposure, materials of such investigations are not submitted to the Directorate, in spite of numerous requests to the managers of organizations... Since those who received more than 25 rem are entitled to 5 monthly salaries, this creates a certain incentive for artificial overexposure in expectation of remuneration. On the other hand, there are also cases when received high doses are concealed." (Document 93, 5 September 1987).

Due to various reasons, there were numerous conflicts at the Chernobyl NPP. People were nervous because of working and living conditions (families lived in Kyiv and Chernigiv, personnel worked on shift basis and stayed at Zelenyi Mys settlement), there were tensions about distribution of apartments in Kyiv, questions on possibilities of keeping these apartments etc. Thus, on 20 August 1986, in the dormitory of Polessky technical college, where about 800 construction workers of Chernobyl NPP were quartered, there was an appeal to go to Kyiv to clarify the issue of apartments allocation. Of 1400 workers 700 families received flats in Kyiv and Chernigiv, but remaining 680 were worried. (Document 61).

Personnel of ChNPP protested against changes in duration of shifts (the plan was to introduce 8 hour shifts instead of 12 hour). They argued that this will take much more time for transportation, condition for rest would be worse and so on. Active discussions among people were triggered by article in central newspapers and film "Chernobyl. Two colors of time".

> "Main points of the discussions:
> - real cause of the accident (whether it's faulty design or mistakes of the personnel) is not established;
> - there was no analysis of the action of personnel - where sacrifices were justified, and where not;
> - still there is no model for actions of the personnel in case of major accident, to avoid panic or "heroism";
> it is not clear, what to do with those whose actions had led to the accident;
> - Ministry of Health of the USSR is obviously hiding the effects of exposure both in low and high doses. This contradicts the policy of "glasnost" and leads to neglecting of radiation protection norms, which can damage the health of current and future generations. (Document 114, 8 August 1988)

Further problems appeared when it became necessary to relocate NPP personnel and their families to the new city of Slavutich. Many refused to leave their Kyiv and Chernigiv apartments. There were much protest because of information that Slavutich is located on contaminated site (Documents 93, 102). Investigation demonstrated that permissible limits in the city of Slavutich are not exceeded, but there are some "hot spots" in nearby forests. On the 2 October 1987, the decision to start settling the city of Slavutich was made, but additional measures like removal of contaminated soil and forest were recommended (Document 97).

According to the report of 28 June 1988, morbidity and mortality of population in Narodichi, Ovruch and Luginy district follow usual patterns. To normalize the situation, replacement of roofs and fences, improvement of dusty roads were started in these rayons. Special measures for additional supply of clean milk top these rayons during summer period were approved, but the request to provide additional food supply was refused (Document 111).

Annex: translated documents

Document 4.

SECRET

TO THE CHAIRMAN OF THE COMMITTEE OF STATE SECURITY OF UKRAINIAN SSR
Colonel-general
Comrade FEDORCHUK V.V.
Kiev

SPECIAL COMMUNICATION
On emergency shutdown of unit 1
of the Chernobyl nuclear power plant

According to information received on 19 February of 1979 by the KGB Department, at 23:40 18 February unit 1 of the Chernobyl nuclear power plant was shutdown by emergency activation of automatic safety system AZ-5. Investigation of the special technical commission, created by the administration of the NPP established that the cause of the shutdown was switching off of main circulation pumps, supplying cooling water in the reactor, due to permeation of air in hydrosystem. In accordance with technological norms, operating reactor is cooled by 4 main circulation pumps, of which one is permanently kept in reserve. During 18.02.79 the reserve pump was repaired and water from unit's hydrosystem was used for lifting pump's rotor. Upon completion of the reaper at 23:05, to avoid loss of desalinated water, workers discharged backwater through closed loop drainage device. During this process air penetrated in the hydrosystem, thus causing misfunctioning of pumps.

The Commission concluded that the cause of penetration of air in hydrosystem is technical imperfection of the drainage device laid down in the design. In connection with this, the nuclear power plant managers summoned representatives of the design institute from Leningrad, to prepare technical recommendation on the mentioned device.

After the liquidation of the emergency by 6 am of 20 February unit 1 was put into operation at prescribed power. As a result of its shutdown, the national economy have not received 11.5 million KWt of electricity.

Chernobyl rayon Committee of the Communist Party of Ukraine and Oblast Committee of the Communist Party of Ukraine were notified on this fact.

Reported as information.

Head of the Department of KGB of Ukrainian SSR
for the city of Kiev and Kiev oblast
major-general N.Vakulenko

«21» February 1979

Resolution on the document: «c[omrade]. Zubatenko N.I. For consideration. *Fedorchuk.* 21.2.».

SA SSU. — F. 65. — File. 1. — V. 5. — Pages. 30–31.
Original. Typewritten.

Document 75.

SECRET

Extract

From the report on the situation at the Chernobyl NPP region

[...] When interviewed, the Chief Engineer of Chernobyl NPP Shteinberg N.A. stated, that it is not advisable to put Unit 3 of Chernobyl NPP into operation, and that he proposed to the top management of *"Minatomenergo"* to put it up into conservation. He also informed that the top management of *"Minatomenergo"* and Chernobyl NPP studies a possibility of penetrating the sarcophagus of Unit 4, because 56 fuel assemblies 16 m long each loaded with uranium are buried in the used fuel storage. Under certain situation these circumstances can lead to explosion. In individual interviews scientist representing Kurchatov Institute and *"Minatomenergo"*'s Research and Design Institute also said that it is unwise to rehabilitate Unit 3 [...] Serious specialists motivated this opinion by the damage to health of many people who would be involved in rehabilitation, and huge material costs (taking into account the permissible dose loads it is planned to engage no less than 25 thousand people).

The dates of putting Unit 3 into operation appeared unrealistic due to extremely unsatisfactory organization of rehabilitation works, and even now the contractor for the work has not been approved.

In October 1986 the Director of the NPP signed a document that all chambers of Unit 3 building were desactivated by 95 %, while the investigation carried out in December 1986 determined that of 1180 chambers only 80 were desactivated, and no one even opened remaining chambers.

According to the reports of NPP management, in 1986 more than 390 tons of highly contaminated 4th reactor debris were thrown down from the roof of Unit 3, although, according to expert estimates, these figures are significantly exaggerated because the roofing could not sustain even one half of this mass.

There was an opinion expressed that due to unjustified involvement of military personnel into clean up of the roof of reactor 3, more than 3 thousand servicemen were irradiated, because the radiation levels on the roof of the reactor were not 500, but in some areas more than 10 thousand roentgens per hour [...].

The Chief of Special Department of KGB of USSR
for <acronym could not be deciphered>
Major-general Mironiuk

1 February 1987

✧ KURRI-KR-21 (1998) http://www.rri.kyoto-u.ac.jp/NSRG/reports/kr21/KURRI-KR-21.htm

Research Activities about the Radiological Consequences of the Chernobyl NPS Accident and Social Activities to Assist the Sufferers by the Accident

✧ KURRI-KR-79 (2002) http://www.rri.kyoto-u.ac.jp/NSRG/reports/kr79/KURRI-KR-79.htm

Recent Research Activities about the Chernobyl NPP Accident in Belarus, Ukraine and Russia

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