The Causes and Scenario of the Chernobyl Accident, and Radioactive Release on the CHNPP Unit-4 Site

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Abstract

On the basis of analysis of old and new data, a realistic version regarding the causes of the Chernobyl accident was developed. In contrast to the previous official versions, this version gives a reasonable explanation to the accident process itself and the various circumstances around the moment of the accident that have not been properly explained up to now. According to this version, the personnel of the Unit-4 rushed to push the emergency shutdown button, AZ-5 after the first explosion occurred in the reactor core, and the seismic impact by the second explosion, which was more intensive than the first one, was registered at three seismic stations located 100 – 180 km from the CHNPP. Little-known experimental data regarding the nuclear fuel release around the 4-th Unit building are also presented.

1. Causes of Chernobyl accident: final choice between two versions

1.1. Two points of view

There are various explanations for the Chernobyl accident. Up to 2002 they can be counted more than 100 versions. However, from the point of view of reactor physics, only two versions can be deemed reasonable. The first one was reported in August 1986 [1], its essence being that at night on 26.04.86 the personnel of the CHNPP Unit-4 have outrageously violated the reactor safety regulations 6 times during the setting and executing process of the electrical test. The last violation was so outrageous that 204 control rods out of 211 regular ones (i.e. more than 96%) have been drawn out from the reactor core. The reactor safety regulations required meanwhile that "When the operational reactivity margin be reduced to 15 rods, the reactor should be shut down immediately" [2, p 52]. Moreover, the personnel have preliminarily switched off almost all of the emergency protection devices. While the reactor safety regulations stated that "11.1.8. Any interference in protection devices, automated protection mechanisms and blockage devices is forbidden, except for system malfunction cases [2, p 81]". These personnel actions have caused the reactor going out of control, followed by the uncontrolled chain reaction and finished with the thermal explosion of the reactor. In [1] "a careless reactor operation" has also been mentioned as well as the lack of understanding by the personnel about "the peculiarities of the reactor technological processes" and a loss of the "risk feeling" by the reactor personnel.

In addition, some specific features of the RBMK reactors have been pointed out that "helped" the personnel in bringing the serious nuclear accident to international catastrophe. In particular, "the reactor designers have not considered a possibility of such situation that the security system signals capable of preventing the accident would be intentionally disconnected from the technical protection system under the condition of the violations of the reactor safety regulations, only because they deemed such factor combination impossible". One can not object against the designers' opinion because the intentional disconnection and violations meant the "grave digging" that no-one is keen in. The final conclusion was stated as "the primary cause of the accident was the hardly possible combination of violations of safety and exploitation rules committed by the personnel of the Unit-4" [1].

In 1991 the second official governmental commission, organized by Governmental Committee for

Atomic Power Supervision (GCAPS) and composed of various NPP operators, has produced another explanation for the causes of the Chernobyl accident. The main idea provided by the second commission was that certain "construction defects" present in the Unit-4 reactor "helped" the reactor personnel to bring the reactor to explosion. The positive steam coefficient and the installation of long (until 1 m) graphite displacers of water at the end of the control rods are usually named as the main defects. The neutron absorption capability of the named displacers is lower than that of water. Therefore, their simultaneous insertion into the reactor core after the AZ-5 button pressing has displaced the water from technological channels. This, in turn, has added so much positive reactivity that the remaining "effective" 6-8 rods have no longer been capable to compensate it. Thus an uncontrolled chain reaction has started in the reactor, which has ended by the thermal explosion of the reactor.

After all, the pressing of the AZ-5 button is considered to be the starting accident event, having initiated the rods' moving into the reactor core. Water displacement from the lower parts of technological channels has caused the increase of the neutron flux in the lower part of the reactor core. Local thermal loads in technological channels have exceeded the relevant mechanical strength limits. Breakage of several zirconium tubes of technological channels led to partial detachment of the reactor cover plate from the reactor casing. It caused multiple breakages of technological channels and the wreckage of the rods that were on their half-way to the lower position.

Consequently, scientists and the reactor designers were accused of the accident, as they created the reactor and the graphite displacers, while the personnel on duty had nothing to do with the causes of the accident.

In 1996 the third official governmental commission, also dominated by the former NPP operators, has confirmed the conclusions of the second commission after having analysed the cumulative materials.

1.2. Balance of standpoints

As the years passed, both parties have been keeping up their own standpoints. It is a curious point that the three official governmental commissions (all of the commissioners being highly experienced authorities) have reached absolutely opposite conclusions based on the same materials. There appears a general impression that suggests some kind of concealment in either the research materials or the commissions' functioning. Especially, in the reports of these commissions, a series of key issues at the critical moment of the accident seem to be not described, or too simply described. Probably this is the reason why none of the parties could indubitably prove its case.

The 'criminal relation' between the reactor operators and its designers remained unclear, in particular, due to the fact that during the electrical test "only the operation factors important for the analysis of the test results were registered" [4]. The personnel is explained the situation as such. It is strange, however, that the personnel failed to register a series of main operation factors that were subject to automatic and continuous measurement (e.g. reactivity). "Therefore the accident development was reconstructed by mathematical simulations of the Unit 4, using the DREG printouts, the registered data and the interrogation of the reactor personnel" [4].

In this way, a long contradiction between scientists and operators has urged the need for an impartial study of all the accident-related data and materials accumulated during the last 15 years. This research should be on the leading principle of the Academy of Sciences, i.e. every statement needs convincing proof and every process needs natural and reasonable explanation. The most important results of such study are set forth herein.

1.3. The AZ-5 button pressing or doubts turning to suspicions

Scientists are commenting on the numerous documents produced by the governmental commissions (the Commission, afterwards) [1] that, if someone reviews the documents quickly, he has an impression of a well-composed and consistent picture of the Chernobyl accident. A closer look, however, leaves a feeling of certain vagueness, as if there were either an incomplete investigation or withholdings of certain information by the Commission, e.g. concerning the AZ-5 button pressing episode.

"At 1 h 22 min 30 sec, the operator saw the program printout stating the operational reactivity margin has reached the limit requiring the immediate shut-down of the reactor. The personnel disregarded the data and the test was launched.

At 1 h 23 min 04 sec, the emergency stop valves (ESV) were closed at turbogenerator No 8…The available emergency protection system for ESV closing …was blocked to assure the possibility to repeat the test in case the first attempt fails...

In a certain period of time the slow power rising was noted.

At 1 h 23 min 40 sec, the operators' chief ordered to press the emergency protection button AZ-5 that initiates the insertion of all the emergency protection control rods into the reactor core. The rods started moving down, but in a few seconds the blows were heard …."[4].

The AZ-5 button is usually the last resort to be pressed in case there is an urgent emergency process within the reactor that can not be stopped by other means. In the quoted evidences, however, there was no reason for pressing the button, as there was no emergency process developing.

The testing period was initially fixed as 4 hours, and the quoted texts prove that the new attempt of repeating the test was planned by the shift personnel, which will take another 4 hours. During the test itself, i.e. on 36-th second of the experiment, however, the operators suddenly changed their opinion and started shutting down the reactor. One must have in mind that 70 seconds ago they refused the same procedure despite a highly risky situation and contrary to the requirements of the reactor safety regulations. All reporters have noted the groundless pressing of the AZ-5 button [5,6,9].

In addition, "The combined study of both the DREG printouts and teletypes indicates specifically that the 5-th category emergency signal … AZ-5 appeared twice, the first one was recorded at 1 h 23 min 39 sec" [7]. But there are also additional data stating the AZ-5 button was pressed three times [8]. The question therefore is: why was the second and the third pressing needed, if the "rods started to move down" after the first pressing? Besides, when the testing was keeping up the initial plan, why should the shift personnel be so nervous? So, physicists started suspecting that at 1 h 23 min 39 sec or earlier some serious emergency did arise, which has made the shift personnel to change their plans, even at the cost of giving up the electric test program that could cause them serious administrative and other punishments. However, the issue was not subsequently reported by either the Commission or the shift operators.

This suspicion grew, as the scientists studying the causes of the Chernobyl accident have found out the asynchronous records within the original proving documents (DREG printouts and oscillograms). The suspicions grew even more when they found out they were given not the originals, but the copies thereof, "copies lacking the timing marks" [6]. That was a very likely attempt to mislead the scientists in respect of the real chronology of the emergency process development. And the scientists had nothing to do but say that "the most completed accident chronology is available…only until the test beginning at 1 h 23 min 04 sec 26.04.86" [6]. The subsequent "event information has essential gaps….and the accident chronology is highly contradictory" [6]. The above-cited scientific-diplomatic wording means practically the lack of credit to the copies presented for research.

1.4. Motion of the control rods

The majority of the afore-mentioned contradictions can be found in the information covering the issue of the control rods motion into the reactor core after the AZ-5 button pressing. One must bear in mind that after the AZ-5 button pressing all control rods had to be moved into the reactor core, 203 of them being from the upper limit stop switches. Consequently, by the moment of explosion they were to be moved to the equal depth into the reactor core, which had to be registered with the selsyns pointers in the Unit-4 control room. The real picture is quite different. Some quotes below would be helpful:

"The rods started moving down…."[4]. No more records.

"01 h 23 min – strong blows, control rods stopped before having reached their lower limit stopswitches. Power supply key was switched off". This is a quote form the operation log.[9].

"…approximately 20 rods kept staying in the upper position, while 14-15 rods were plunged into the reactor core not more than 1…2 m…"[16].

"…displacers of the emergency control rods have passed the distance of 1. 2 m and displaced completely the water columns thereunder…" [9].

"The neutrons absorbing rods started moving down and stopped almost immediately, their penetration to the reactor core being around 2-2.5 m instead of normal 7 m" [6].

"The investigation of the rods' final positions under the selsyns pointers data showed approximately a half of rods stopped at a depth of 3.5 to 5.5 m" [12]. The question therefore is: where was the second half of the rods, provided all of them started moving down after the AZ-5 button was pressed?

"The positions of the selsyns pointers as conserved after the accident gives an assumption that… some of the rods reached the lower stop switches (the total of 17 rods, 12 of them being from the upper stop switches) [7].

The afore-stated quotes show various official documents describe differently the rods' movement process. The oral evidence by the personnel indicates that the rods have moved into the core up to 3.5 m and stopped afterwards. The main proof of the rods' motion into the reactor core is thus an oral evidence by the shift personnel and the selsyns pointers positions in Unit-4 control room. No other proof to the rods' movement was discovered.

Should the pointers' positions be documentary fixed during the accident, these data could serve the basis for reconstructing the accident. However, the afore-said pointers positions were fixed only <u>during the daytime</u> of April 26, 1986" [7], that is 12-15 hours after the accident. This fact can be deemed crucial, because the physicists working with selsyns are fully aware of their crafty properties. The first one is that the pointers of the selsyns-synchroreceivers can take any position in case the selsyns-synchrotransmitters undergo the uncontrolled mechanical impact,. The second property is that the absence of power supply to the selsyns causes the same effect to the selsyns-synchroreceivers pointers. Selsyns are not a mechanical watch fixing the specific moment of the air crash.

Therefore, defining the depth of the rods' insertion into the reactor core at the moment of accident via fixing the selsyns-synchroreceivers pointers' positions in Unit-4 control room 12 - 15 hours after the accident is highly inaccurate method, as the Unit-4 selsyns were exposed to both factors. This is disclosed in document [7], stating that 12 rods after the AZ-5 button pressing have passed the 7 m distance from the upper stop switches to the lower stop switches before the explosion happened. A logical question arises as to how the mentioned distance could be passed in 9 seconds while the normal timing to the same distance makes 18 to 21 seconds [4]. The data are obviously erroneous.

Therefore, the position of the pointers of selsyns-synchroreceivers in the Unit-4 control room as fixed 12 - 15 hours after the accident can not be deemed an objective scientific proof of the rods' insertion into the reactor core after the AZ-5 button pressing. The proof remaining is only the subjective evidence of persons highly interested. The issue of the control rods motion into the reactor core after the AZ-5 button pressing is therefore still pending.

1.5. Seismic impact

In 1995 a new hypothesis has been spread in mass-media, stating that the Chernobyl accident was caused by a 'narrow-beam like' earthquake of 3 - 4 degree which took place near CHNPP approximately

16 – 22 sec before the Chernobyl accident, and this fact was confirmed by the relevant seismogram peaks [10]. The scientists, though, have rejected this version immediately as the unscientific and ill-proved. According to the seismologists' opinion on the issue, an earthquake of 3-4 degree with the epicenter in the north of Kiev region is nonsense.

But in 1997 a serious scientific report was published [21], containing the accurate data on the issue based on the analysis of seismograms obtained from 3 seismic stations located 100 – 180 km from the CHNPP. The data showed that at 01 h 23 min 39 sec (± 1 sec) local time "a week seismic event" happened at the distance of 10 km to the east from CHNPP. The MPVA magnitude of the source defined based on the surface waves amplitudes was coordinated at all 3 seismic stations and was equal 2.5. Its TNT-equivalent was 10 t. It was impossible to estimate the source depth on the basis of the available data. In addition, the low amplitudes level on the seismograms and the one-way location of all seismic stations with regard to the epicenter gives the geographic coordinates error that can not to be less than 10 km. Therefore, this "week seismic event" could really happen at the CHNPP location [21].

These results made the scientists to reconsider more attentively the geotectonic hypothesis, because these seismic stations appeared to be the supersensitive ones that could register the underground nuclear tests all over the world. Therefore, the fact of an earthquake 10 – 16 sec before the official moment of the Chernobyl accident became an indisputable argument that no one could ignore.

The only strange circumstance with regard to these seismograms was the absence of peaks at the moment of the 'official' explosion of the Unit-4. We can say the following: the seismic devices registered a seismic event no one else could notice, while the Unit-4 explosion, which shook the earth and was felt by many persons, passed the attention of the seismic devices. One has to note that the devices in question are capable of detecting the explosion of some 100 t of TNT at a distance of 12 000 km, while the Unit-4 explosion was equal to 10 t of TNT and the distance was 100-180 km.

1.6. The new version

Numerous contradictions listed above as well as the lack of clarity in the materials in respect of various issues have strengthened the scientists' suspicions regarding the facts' concealment by the reactor operators. As the time passed, a revolutionary concept has been growing with the scientists – why could not the events happen vice versa? First – the double explosion, 500-meters high violet flames over the reactor, building of the Unit-4 shuddering all over, concrete beams shaking and steam-saturated air blast bursting into the Unit-4 control room. The general lightning went off, and only three accumulator-fed lamps kept functioning.

The personnel in the control room could not miss that. After having recovered from the first shock, the personnel rushed to press the AZ-5 button. But it was too late. The reactor was already destroyed. The whole story could take up to 10, 20 or 30 seconds after the explosion. Given that, the accident itself could have begun not at 01 h 23 min 40 sec, but earlier, and consequently, the uncontrolled chain reaction began before the AZ-5 button was pressed.

The suggested sequence of events gives a natural explanation for both the urgent multiple pressing of the AZ-5 button and the personnel' nervousness, which happened when they were going to exploit the reactor peacefully at least 4 hours more. This concept explains also the registered peak on the seismic curves at 01 h 23 min 39 sec and its absence at the 'official' moment of the accident. Finally, with this concept a natural explanation can be given to certain events that happened before the explosion and had previously no logical explanation, such as "vibrations", "the increasing boom", "hydroblows" from the central hall, "jumping" of 2000 "biological shield" blocks in the reactor central hall, etc [11].

1.7. Quantitative proofs

The naturalness of the explanations given to a series of unclear events by the afore-stated new concept is a weighty argument in favor thereof. These arguments, however, have mostly of qualitative character, while our implacable opponents could be successfully persuaded only by the quantitative arguments. Therefore, the ‘rule of contraries’ (*reductio ad absurdum*) method will be used for demonstration.

Let us assume the reactor exploded “in some seconds” after pressing of the AZ-5 button and graphite displacers’ moving into reactor core. Such scheme presumes clearly that the Unit-4 was controlled by its personnel till the events started. That is, by the moment the AZ-5 button was pressed, the reactivity was somewhat near 0 β. It is well known that the simultaneous moving of all control rods with graphite displacers into the reactor core can add positive reactivity from 0.2 β to 2 β dependent on the reactor state [5]. Should the sequence of events be the ‘official’ one, the total reactivity could at a certain moment surpass 1 β value, which means the start of the explosive type uncontrolled chain reaction based on prompt neutrons.

Should that be the real accident scenario, the designers of the reactor would share the responsibility for the accident instead of the reactor operators. But should the reactor explode before the AZ-5 button was pressed or at the moment it was pressed, then the reactor reactivity at that moment was already more than 1 β. In this case the fault for the accident falls apparently on the reactor personnel, as they lost control over the chain reaction after 01 h 22 min 30 sec when the reactor safety regulations required the reactor shut down. The question on the reactivity value at the moment of pressing of the AZ-5 button by the personnel has therefore has a fundamental importance.

The Unit-4 reactivity-meter readings could help to answer the above question. These readings, however, were not found among the accident-related documents. The question had been solved by various authors based on the computer simulation of the accident. The possible total reactivity values were obtained within the research process as lying between 4 β to 10 β [12]. In these works the total reactivity balance included mainly the effect of the control rods’ moving into reactor core (up to +2 β), the steam void effect (up to +4 β) and the loss-of-water void effect (up to +4 β). The impact of other processes (cavitation and others) was deemed secondary.

In all these works the accident process began with the AZ-5 button pressing followed by the moving of control rods into reactor core (adding another up to +2 β to the total reactivity). That has caused the beginning of the uncontrolled chain reaction in the lower part of the reactor core, which has led to the breakage of the fuel channels. Then the steam and loss-of-water void effects came into action. They, in its turn, could bring the total reactivity up to +10 β by the end of the reactor life. Our estimations of the total reactivity at the moment of the accident (based on the analog method using the American experimental data) [13], have shown a rather close value of 6-7 β.

Now, assuming the most likely total reactivity value was 6 β and deducting the highest possible +2 β added by the graphite displacers, the final total reactivity value before moving the control rods into reactor core made +4 β. Such reactivity value is enough to cause the immediate destruction of the reactor. The reactor lifetime with such reactivity level makes no more than 0.01-0.02 sec. No personnel, whatever be their experience, could timely react to the appearing threat.

Hence, the quantitative estimations of reactivity before the accident also show the uncontrolled chain reaction began in the Unit-4 reactor before the AZ-5 button was pressed. Therefore, its pressing could not cause the reactor thermal explosion. Moreover, given the afore-stated circumstances, the specific time of AZ-5 button pressing (either before, or within, or after the reactor explosion) was already of no matter.

1.8. What are the witnesses saying?

During the investigation and tribunal the witnesses present in the Unit-4 control room during the accident were actually divided in two groups. The first one, composed of those who were liable by law for the reactor safety, was stating that the reactor exploded after the AZ-5 button pressing. The second group, composed of those bearing no legal liability for the reactor safety, stated the reactor exploded either before or immediately after the AZ-5 button was pressed.

As everyone of them was trying to justify his actions when recalling the events, such evidences have to be treated with some caution. So did the author considering them as supplementary materials. The correctness of our version, however, can be seen even through this stream of justifications. Here is some quoting of the witnesses' evidences.

"The main engineer of the CHNPP second stage, who was in charge of the experiment… reported to me that he has pressed the AZ-5 button, as usually, to assure the reactor shut-down in case of any emergency…" [14].

This quotation is taken from the memories of B.V. Rogozkin who was the shiftman at the CHNPP during the night of the accident. It clearly shows that at first the emergency situation arose at the Unit-4 and then the operators pressed the AZ-5 button. In case of the reactor thermal explosion, the creation and running of the "emergency situation" occurs very fast within a second. Once it arose, the operators had no chance to react it.

"The whole event took 10 – 15 seconds. The vibrations appeared. The boom was growing quickly. The reactor power dropped at first and then started growing out of control. Then followed the several sudden claps and two "hydroblows". The second one was much stronger and came from the central hall. Lightning went off in the control room, the ceiling plates started falling and the equipment went off as well**"** [15].

This is his description of the course of accident (no timing marks mentioned). Another such description was given by N. Popov.

"… a low-toned boom was heard, its source being absolutely unclear, similar to a human groan (the witnesses of the earthquakes and nature convulsions have been reporting similar sounds). The floor and walls shook strongly, dust and small crumbs started falling from the ceiling, lighting went off and then a dull sound came out, being followed with a thunderous burst …"[17].

"I. Kirshenbaum, S. Gasin, U. Lisyuk, who were present in the Unit-4 control room witnessed they heard the order to shut down the reactor just either before or after the explosion" [16].

"At that moment I heard Akimov's order to shut down the reactor. Then immediately the strong rumble came from the central hall." (quote from A. Kuchar evidences) [16].

All these evidences show the moment of the reactor explosion and that of the AZ-5 button pressing almost coincided.

The impartial data also point this important circumstance out. Let us remember that the AZ-5 button was pressed at the first time at 01 h 23 min 39 sec and the second time – two seconds later (according to teletype data). Seismic curves showed the Unit-4 reactor explosion took place within the period of 01 h 23 min 38 sec to 01 h 23 min 40 sec [21]. Bearing in mind that the teletype time shift towards the standard USSR time could be ±2 sec [21], one can firmly assume the moment of the reactor explosion and that of the AZ-5 button pressing almost coincided. This fact implacably denotes the uncontrolled chain reaction to have started in the Unit-4 reactor before the AZ-5 button was pressed.

But which explosion is now under consideration - the first or the second? The answer to this question can be found in the seismic curves and in the witnesses' evidences. Should the seismic stations have registered only one out of the two weak explosions, the natural assumption is that the stronger explosion was registered. According to the witnesses' evidence, the second explosion was the stronger one. It leads us to another firm assumption that the second explosion happened within the period of 01 h 23 min 38 sec to 01 h 23 min 40 sec.

The witnesses' evidences support this conclusion as follows.

“The reactor operator L. Toptunov shouted the reactor power had reached the emergency markup. Akimov shouted loudly: “Shut down the reactor!” and dashed to the control desk. There was the second ‘shut down’ order well heard by everyone. That happened apparently after the first explosion…” [16].

This evidence proves that the first explosion happened before the AZ-5 button was pressed for the second time. This is very important for our further analysis. An easy timing calculation would be of certain use. It is already known that the first AZ-5 button pressing took place at 01 h 23 min 39 sec and the second AZ-5 button pressing took place at 01 h 23 min 41 sec [12]. The time interval between both pressings makes 2 seconds. Viewing the emergency readings of the equipment, analyzing them and shouting “emergency power increase” would take no less than 4-5 seconds. Then one would need another 4-5 seconds to hear that, take the decision, order the reactor shut down, dash to the control desk and press the AZ-5 button. Thus, we have already 8-10 seconds ‘reserved’ before the AZ-5 button pressing. Remember now that by that moment the first explosion happened already. That is, it happened even earlier and definitely before the first AZ-5 button pressing.

How many seconds before the pressing? With regard to the inertness of the human reaction to an unexpected danger, which makes usually at least several seconds, we‘ll need to add another 8-10 sec. So we obtain the total of 16 – 20 seconds ‘reserved’. Should the personnel act two times quicker, we still have 8-10 seconds ‘reserved’.

As the uncontrolled chain reaction finished with the thermal explosion, it had to have started 10 –15 sec earlier. We can therefore ultimately presume the uncontrolled chain reaction started within the period of 01 h 23 min 05 sec to 01 h 23 min 10 sec. Whatever surprising it may seem, the main witness pointed out, when answering the question regarding the adequacy or inadequacy of the AZ-5 button pressing at 01 h 23 min 40 sec (according to DREG), “I did not emphasize on the time – the explosion would have happened 36 seconds earlier…” [16]. That is, at 01 h 23 min 04 sec. As noted above, as early as 1986 the VNIIAES specialists pointed out the same moment as the moment, after which the accident chronology (as reconstructed on the basis of the copies of accident-related documents presented for their study) was uncertain. There seems to be too many coincidences. What mean these coincidences? Apparently, the first accident features (“vibrations”, “unclear boom”, etc.) appeared already 36 seconds before the first AZ-5 button pressing.

The comparison of the accident materials and the witnesses’ evidences (as sited above) allows the conclusion that the first explosion happened within the period of 01 h 23 min 20 sec to 01 h 23 min 30 sec. It became the primary reason for the first AZ-5 button pressing. Remember now that no official commission or any author could give natural explanation to that.

But, why did the Unit-4 operators, being not beginners but an experienced team led by even more experienced the main engineer of the CHNPP second stage, nevertheless lose control over the chain reaction? Their memories answer to this question.

“We never intended to violate ORM and we did not violate it in fact. The violation is a willful disregarding of the devices’ readings, but on April 26th, 1986, nobody saw the ORM less 15 rods… But we evidently failed to notice that…” [16].

“One can never know why Akimov delayed his shut down order. We have been communicating each other, till we were put to different hospital rooms...” [16].

This declaration was written directly by the main participant of the accident events many years after the accident, when he was no more under the danger from either justice, or his former superiors. So he could write frankly. This declaration shows obviously to any reasonable man that the reactor explosion is definitely due to the fault of Unit-4 operators. Most likely the operators were so keen in the risky process of supporting the reactor power that has come to self-poisoning process due to their own fault, at the level of 200 MWt, and ‘failed to notice’ the inadmissibly dangerous rods removing out of the reactor core. And then the personnel “delayed” pressing the AZ-5 button.

That was the immediate technical cause of the Chernobyl accident. All the rest is misinformation (or, at best, just a huge mistake). The time has come to finish the heated discussion on who is in charge of the Chernobyl accident and shifting of the fault to scientists, as the reactor operators normally do. The scientists were right as early as 1986.

2. Accident scenario

2.1. The initial event

The new version permitted to prove the most natural scenario of the Chernobyl accident. By now it looks like as follows. At 00 h 28 min on April 26, 1986, while switching the reactor to the electric tests operation via switching from local automatic control (LAR) system to the power automatic control (AR) system, the operators made an error. Due to this error the reactor thermal power went down to 30 MWt while the reactor neutron power went down to zero and continued like that during 5 min according to the neutron power plotter [5]. The process of self-poisoning by short-life fission products started automatically in the reactor. The process itself contained no threat of nuclear explosion. Moreover, as this process develops, the reactor capability to support the chain reaction declines until the reactor fully stops irrespective to the operators' intentions. Throughout the world the reactor is being shut down in similar cases, and a 1-2 days' break is made till the reactor operation capabilities are restored. Then the reactor is switched in again. This is not an extraordinary process and does not present any difficulties for the experienced personnel of the Unit-4.

But this is a rather bothering and time-consuming procedure for RBMK-1000 reactors installed at CHNPP. In our case it also meant the wreckage of the electrical test plans that could cause various administrative troubles. So, being eager "to finish the testing as soon as possible", as it was later explained by the personnel, they began step-by-step removal of the control rods from the reactor core. Such removal was to compensate the reduction of the reactor power that happened as the result of the self-poisoning processes.

Such procedure was also usual for the Unit-4 reactor and could cause the nuclear accident only in case of excess removing of the control rods from the reactor core. When the quantity of the remained

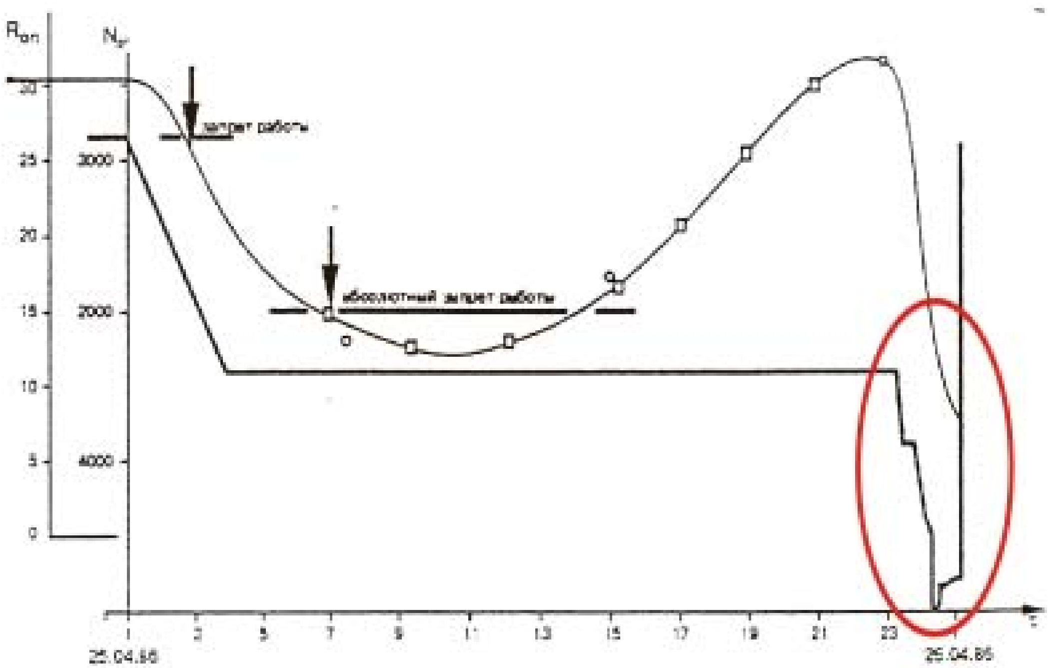

Fig. 1. The power (N_p) and the operational reactivity margin ($R_{оп}$) of the Unit-4 reactor in diapason of the time from 25.04.1986 to the official moment of the accident 26.04.1986 [12]. The pre-accident and accident diapason of the time was marked by oval.

"effective" rods reached 15, the operators were to shut down the reactor, as it was their definite official duty.

By the way, similar violation happened for the first time at 07 h 10 min on April 25, 1986. That is, almost one day before the real accident, and this violation continued till 14 h 00 min (Fig, 1). It is interesting to note that within the course of this violation the operating shift teams and the shiftmen of the Unit-4 and of the whole CHNPP changed. Still, none of them gave any alarm, as if everything was under control, though the reactor was already on its breakpoint. The unwitting conclusion arises that the similar violations were common not only within the course of the 5-th shift of the Unit-4. This conclusion is supported by the evidence of I.I. Khazachkov, who was the day shiftman of the Unit-4 on April 25, 1986:

"We had many experiences of excessive removal of rods, I'd say – and nothing happened...", "No one of us could envisage those actions could cause nuclear accidents. We knew these actions were prohibited, but we never thought…" [18].

The second time the violation took place on April 26, 1986, soon after midnight. But for some reasons the operators did not shut down the reactor and continued the rods' removal. As a result at 01 h 22 min 30 sec the ORM reduced to "effective" 6 –8 rods. But this fact did not stop the personnel and they began the testing. Given that, we can definitely assume the operators continued the removal of the control rods till the explosion moment. This point is supported by the evidence that "the reactor power started growing slowly" [4] and the experimental curve of the timing markups of the reactor power changes [12] (Fig. 2).

No one throughout the world treats the reactor this way, as there are no technical means to assure the safe control over the self-poisoning reactor. The personnel of the Unit-4 evidently had no such means at their disposal. Definitely no one intended to make the reactor explode, so the excessive (more than standard "effective" 15) removal of the control rods was effected instinctively. From the point of view of a professional it was a pure venture. Why they did embark to it is a separate issue to be discussed.

Somewhere between 01 h 22 min 30 sec and 01 h 23 min 40 sec the intuition betrayed the operators and the number of "effective" rods remained in the reactor core appeared to be less than 6-8. Maybe 2 or 0. The reactor switched automatically to the support of the chain reaction based on prompt neutrons. There are no technical means to assure the reactor control within the similar regime, and such means are unlikely to be ever created. Therefore, during some fractions of seconds heat release in the reactor increased 1,500

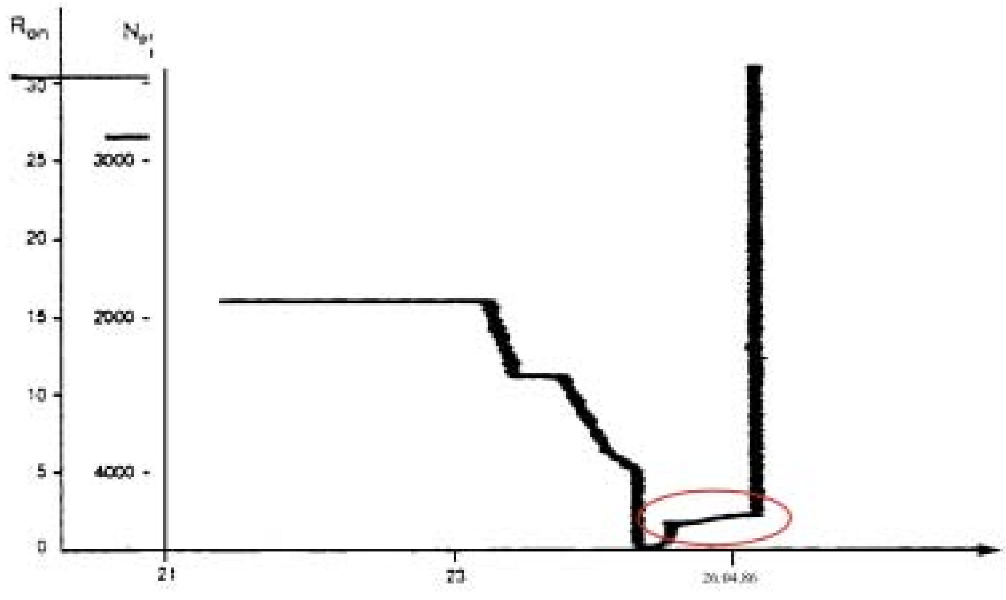

Fig.2. The change of the power (N_p) of the Unit-4 reactor in the diapason of the time from 23 h 00 min 25.04.1986 to the official moment of the accident 26.04.1986 .(The magnified part of the curve in Fig. 1). The unabated increasing of the reactor power calls attention.

times and nuclear fuel was heated up to 2,500 –3,000 °C [5,6]. Further the process named ‘the thermal explosion of the reactor’ began. The consequences thereof made CHNPP ‘famous’ throughout the world.

Therefore, the excessive rods’ removal from the reactor core should be considered more certainly as the event that initiated the uncontrolled chain reaction. The similar process happened in 1961 and in 1985 during other nuclear accidents that finished by the reactor thermal explosion. After the destruction of the fuel channels the reactivity increased due to both steam effect and void effect. To estimate the individual contribution of each of the stated factors to the final result, one needs a detailed computer simulation of the most intricate and at least the studied of the second phase of the accident.

The afore-stated scenario of the Chernobyl accident looks much stronger and seems to provide a far more natural explanation than the version based on the idea of moving the rods into the reactor core after pressing of the AZ-5 button. Because the quantitative effect data of this moving as given by different authors are scattering from rather serious 2 β to negligibly small 0.2 β, no one can say which of them has ‘worked’ during the accident. In addition, “as a result of studies by various teams of specialists….it was found out that one positive reactivity input via moving of RCPS-rods into the reactor core after AZ-5 button pressing**, was not enough,** provided all the feedbacks are taken into consideration, to reproduce the power peak, the start of which was recorded by the central control system CCS SKALA of the CHNPP Unit-4” [7] (Fig 1).

At the same time it has long been known that the control rods removal out the reactor core can add a bigger reactivity by itself – above 4 β [13]. That is the first issue. The second one is that the rods’ insertion into the reactor core still has no scientific proof. The new version shows meanwhile that the rods could not be placed into the reactor core, because by the moment of pressing the AZ-5 button neither the rods, nor the reactor core existed. Thus the version stated by the personnel meets the qualitative arguments’ check but fails to meet in terms of quantitative arguments and, therefore, should be shelved from now on, while the scientists’ version has gained the additional quantitative support.

2.2. The “first explosion”

The uncontrolled chain reaction within the Unit-4 reactor began in a certain (rather small) part of the reactor and caused local overheating of cooling water. It is most likely to have started in the south-east quadrant of the reactor core at the height of 1.5 – 2.5 m above the OR-system. When the steam-water blend pressure exceeded the break point for the zirconium walls of the fuel channels, the channels were torn apart.

The extremely overheated water has turned into a high-pressure steam almost in a moment. The steam, while expanding, pushed up the heavy (2,500 t weight) E-system. The breakage of some of the fuel channels appeared to be enough to assure this effect. The initial phase of the reactor destruction was finished thereby and the second phase began.

While going up, the E-system was tearing the rest of the fuel channels like in the domino effect. Many tons of the overheated water have turned into steam almost in a moment, and the steam pressure pushed up the E-system up to the high of 10 – 14 m. The mixture of steam, graphite parts, nuclear fuel, parts of the broken fuel channels and other constructive elements of the reactor core rushed to the crater. The E-system itself, after swinging around in the air, fell back onto the crater having thereby crushed the top of a reactor core and causing the additional release of radioactive substances to the atmosphere. The double character of the “first explosion” can be explained by the blow caused when the E-system fell down.

2.3. The “second explosion”

In parallel to the afore-said mechanical processes various chemical reactions started in the reactor core. The exothermal steam-zirconium reaction is the most interesting one. It normally starts at 900°C and

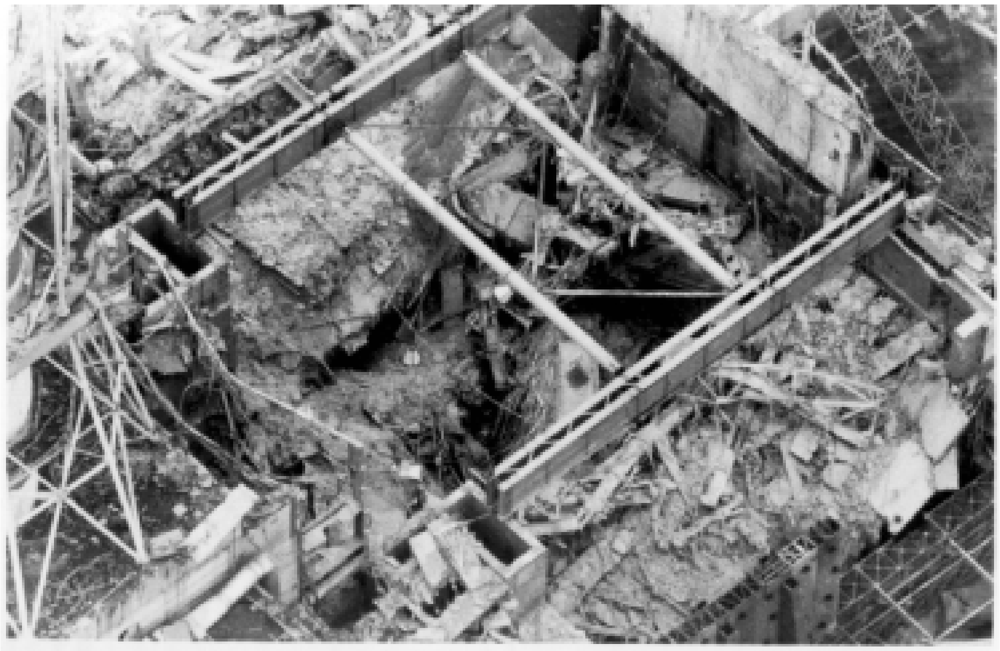

Photo 1. The destroyed Unit-4 reactor (top view).

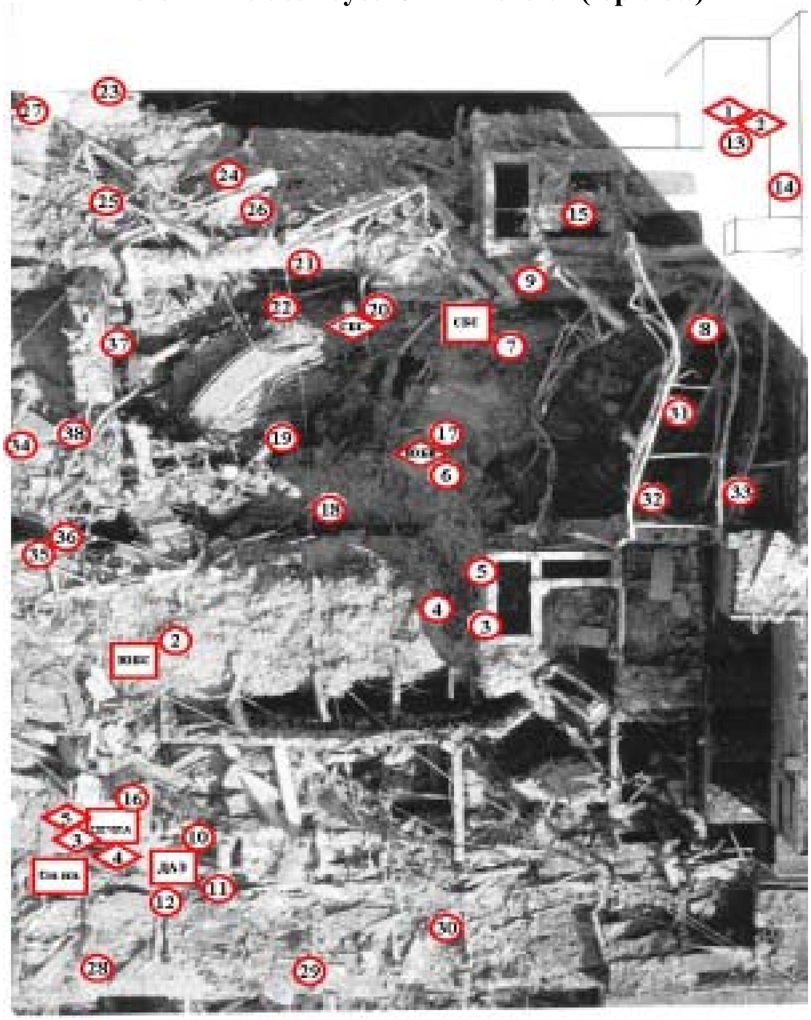

Photo 2. The view to the Central hall of the Unit-4 reactor(side view). The points of the fuel sampling for the following investigations were marked by circles.

proceeds intensively at already 1,100°C. Its possible role was studied in more detail in work [19]. This work showed that with regard to the conditions of the Unit-4 accident only this reaction itself could generate more than 5,000 m^3 of hydrogen.

When the E-system went into the air, the afore-said mass of hydrogen burst from the reactor into the central hall. While mixing with the air of the central hall, it created a detonation air-hydrogen blend. Then the blend exploded due to either a casual spangle or red-hot graphite pieces. According to the type of damages caused to the central hall, the explosion was rather massive - an analogy to a famous "vacuum bomb" explosion. It ruined the Unit-4 reactor building. Its outward results look rather impressive on the May 1986 photo. Two of them (Photos 1 and 2) are given as an example. Later the photos describing the explosion effect in under-reactor premises were obtained.

After both explosions the formation of the lava-like fuel-continued materials started in the under-reactor premises. But this unique phenomenon is the result of the accident and is worth a separate detailed consideration.

3. The fuel release to the Unit-4 site

3.1. First measurements of the radiation situation

After both explosions the nuclear fuel fragments, graphite fragments and radioactive constructions fragments were scattered around the reactor building. Main part of the release was concentrated in heaps near the walls of the Unit-4 building and on the roof of nearest building of the second stage of CHNPP. The radius of the reactor core fragments scattering reached 100 m. Some fragments were even found at a distance of 200 m. In addition to this release the fuel "hot particles" were falling on the Unit-4 site until 6 May 1986 (active stage of accident).

During the first days after the accident, exposure rate measurements were carried out by different means and improvised technical devices, via walking on foot or military transport with no accurate fixing of the measurements points coordinates (x,y,z) on maps.

Exposure rates on the Unit-4 site varied greatly – from tens of milli-Roentgen to thousands Roentgen per hour. Maximum value was reported near the destroyed Unit-4 and near the reactor core fragments.

As the measurements of the radiation situation were fulfilled under the conditions highly dangerous for the life of the investigators, they could not be systematic. The general radiation situation at the Unit-4 site by April 26, 1986, as reconstructed by the scientists of the "Khurchatov's Institute", Radium Institute and ISTC "Shelter" on the base of systematization and analysis of the first measured data, is shown in Fig

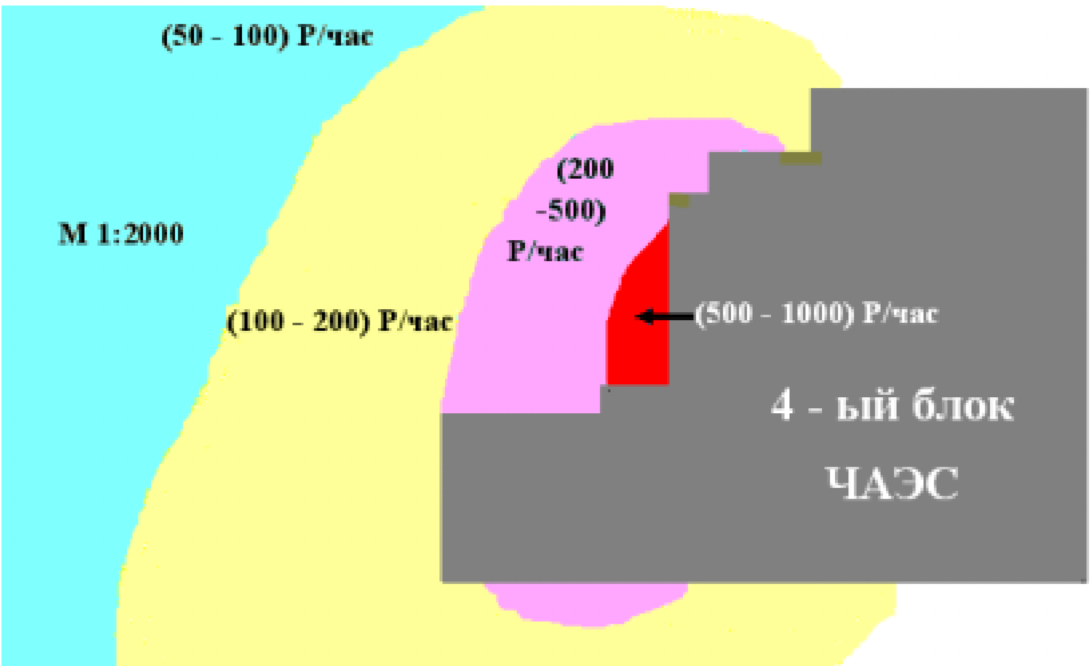

Fig. 3. The radiation situation on the CHNPP Unit-4 site at 26.04.1986 (Р/час=R/hr).

3 [20].

3.2. Radiation measurements from helicopters

On May 22, 1986 the "Radium Institute" scientists began studying the gamma-field distribution around the Unit-4 site from helicopters type MI-8T. It flied over 12 routes along the CHNPP building with the 25 m interval from north to south and back. The site surface was scanned with the collimated detector with the NaI-crystal at the height of 200 m. The lead collimator assured the coverage area of the site surface at around ≅30 m in diameter. The initial calibration was fulfilled during the helicopter hang-up over the radioactive territory out of the Unit-4 site, where the concentration of the radionuclides and exposure rates were measured previously.

According to the "Radium Institute" estimations, the amount of the nuclear fuel released around the Unit-4 site (that remained at the moment of measurements) was 700 kg with the error ±30% [20].

Somewhat later (from 30 May 1986 to 09 June 1986) the joint team of "Khurchatov's Institute" and of the Ministry of Geology started measuring from helicopters the radiation situation at the Unit 4 site and near the destroyed reactor. The measurements were taken over the reactor and near it using the measuring

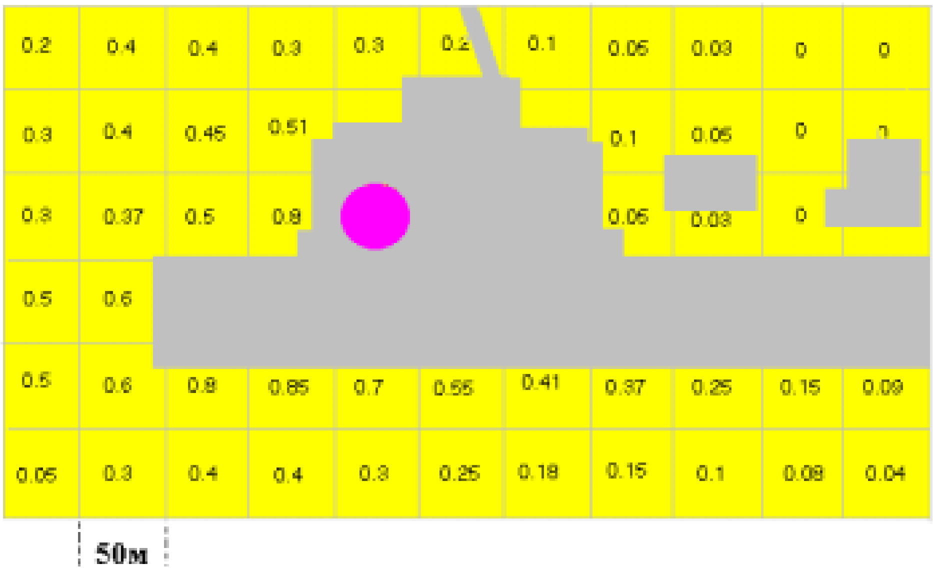

Fig 4. The nuclear fuel distribution, released to the Unit-4 site at the accident (relative unit).

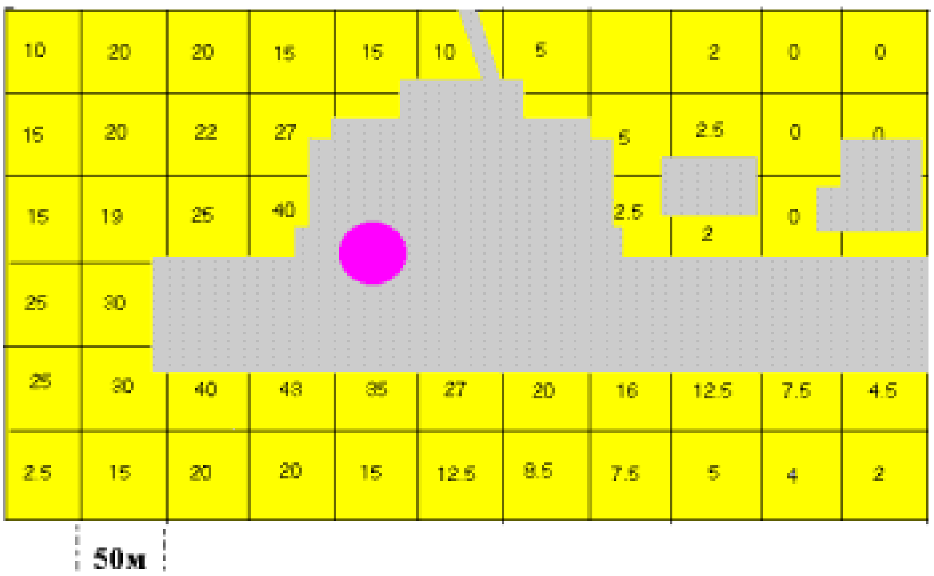

Fig. 5. The nuclear fuel distribution, released to the Unit-4 site at the accident (in kg on site 50×50 m^2).

apparatus system placed at the helicopter type Ka-32CH. It allowed the surface scanning for the exposure dose at a height of 200 m and higher over the investigated surface.

Within the course of measurements the maps of the exposure rates at the reactor zone, the north and south drum-separators zone and at the other parts of the Unit-4 was obtained. Around 2,000 measurements were done on the surface sectors with the area of 10×10 m^2 to 20×20 m^2.

The chart of the relative gamma-fields distribution at the Unit-4 site is shown in Fig 4. The errors of these measurements are evidently much less than the errors of the absolute measurements. The results of this measurements permitted to estimate the total fuel amount at the Unit-4 site as 600 ± 300 kg [20].

The data obtained by both teams permitted, after certain analysis, to produce the most reliable chart of the fuel distribution at the Unit-4 site, averaged by 50×50 m^2 sectors. For that purpose the quantitative data of the Radium Institute team were averaged and marked on the chart according to the relative measurements of the Khurchatov's Institute" team. Then the special program calculated the most probable correlation coefficient. As a result the full fuel amount at the Unit-4 site (outside the actual Unit-4 building) was estimated as 600 kg (-180, +300). The final estimations are shown in Fig. 5 [20].

The total error appeared to be rather serious. Therefore the investigators wanted to repeat the measurements work with more accuracy. But in some time the area of the Unit-4 site started being filled with different materials and then the concreting works started in order to cover the site surface. Therefore the repeated measurements appeared to be impossible. Still, the main result obtained during these measurements was that no more than 1 ton of the nuclear fuel kept staying around the Unit-4 site. The later measurements taken by boring the wells at the territory of the Unit-4 site supported this estimation, 600± 200 kg [20].

4. Some words on the adequacy of DREG printouts

One can object that the afore-stated new version of the Chernobyl accident contradicts the official chronology, based on the DREG printout as shown, for example, in [12]. The author does agree there is a contradiction, but a closer look into the stated printouts ultimately shows that the official chronology is not proved with the other accident-related documents starting at 01 h 23 min 40 sec and also contradicts completely both the reactor physics and the witnessed evidences. The VNIIAES specialists have paid attention to that as early as 1986 [4,5]. It was pointed out above already.

For example, the official chronology based on the DREG printout describes the accident process as follows:

- 01 h 23 min 39 sec (on teletape) - AZ-5 button pressing.
- 01 h 23 min 40 sec(on printout of DREG) AZ-5 button pressing.
- 01 h 23 min 41 sec (on teletape) - AZ-5 button pressing.
- 01 h 23 min 43 sec (on printout of DREG) - An emergency increasing of the reactor power.
- 01 h 23 min 45 sec (on printout of DREG) - A reducing a amount of the pumped cooling water to 18 000 m^3/h.
- 01 h 23 min 48 sec (on printout of DREG) - An increasing a amount of the pumped cooling water to 28 000 m^3/h.
- 01 h 23 min 49 sec A signal of the emergency protection "The pressure increasing in the reactor volume".

That is, according to the official chronology an emergency increasing of the reactor power began 3 seconds after of the AZ-5 button pressing (on DREG).

While, the witnesses evidences describe the accident process in the opposite order:

"…I was diverted to something. Maybe, it was the Toptunov's cry: "The reactor power increases with an emergency speed!". I am not sure in accuracy of this phrase, but the sense remember just such. Akimov dashed to the control desk quickly, opened the cover and pressed the AZ-5 button …". [22].

The main witness describes the same order of the accident events, which was shown above already [16].

According to the witnesses' evidences, at first an emergency increasing of the reactor power began and then the AZ-5 button was pressed some seconds after it.

The official chronology contradicts to the reactor physics also. As directed above, a reactor life-time at a reactivity value 4 β and above is a value of order 0.01-0.02 sec only. But, according to the DREG printout, 6 seconds was needed from the moment of an emergency increasing of the reactor power before the fuel channels began to break down only.

Nevertheless, for some reason absolutely, almost all of authors neglected this circumstance and assumed the DREG printout as a document, that adequately described the accident process. But it is wrong. The CHNPP personnel have known about it very long ago. The DREG program at CHNPP "was recognized as a background program, which was interrupted by all other functions" [22]. Consequently "… event time of DREG is not the true event time, but it is the time of signal recording about the event in a buffer (for a following tape recording)" [22]. By other words, the pointed events occurred, but at other, earlier times.

This very important circumstance was concealed from scientists 15 years. As a result of it, dozens of scientists worked during a lot of time in vine, investigating physical processes that led to such grand accident. They did their investigations based on the contradicted DREG printout and the evidences of witnesses who were liable by law for the reactor safety and therefore were strongly interested personally in an expansion of the version – "reactor exploded after the AZ-5 button pressing**".** Meanwhile, for some reasons, they neglected the witnesses, bearing no legal liability for the reactor safety and therefore were more objective. And this most important recently opened circumstance confirms the conclusions of this work additionally.

5. The conclusions

1. The initial cause of the Chernobyl accident was the unprofessional actions of the 5-th shift personnel of the Unit-4. Most likely the operators were so keen in the risky process of supporting the reactor power, which has come to self-poisoning process due to their own fault at the level of 200 MWt, and 'failed to notice' the inadmissibly dangerous rods removing out of the reactor core. And then the personnel "delayed" pressing the AZ-5 button.
2. The motion of the graphite displacers into the reactor core could not be the cause of the Chernobyl accident, because at the moment of the first AZ-5 button pressing (01 h 23 min 39 sec) there did not exist the control rods and the reactor core already.
3. The reason for the first AZ-5 button pressing was the first explosion of the Unit-4 reactor, which happened in the period from 01 h 23 min 20 sec to 01 h 23 min 30 sec and destroyed the reactor core.
4. The second AZ-5 button pressing happened at 01 h 23 min 41 sec and essentially coincided with the second, more intensive explosion of air-hydrogen blend, which destroyed the Unit-4 reactor division building.
5. The official chronology of the Chernobyl accident, based on printout of DREG, describes the accident process inadequately after 01 h 23 min 40 sec. The VNIIAES specialists were the first men who paid an attention to it in 1986. It is necessary to start the official reconsideration of the accident chronology, taking into account the new circumstances, opened during the last years.

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