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ON THE POSSIBLE MAGNETIC MECHANISM OF SHORTENING THE RUNAWAY OF RBMK-1000 REACTOR AT CHERNOBYL NUCLEAR POWER PLANT

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The official conclusion about the origin of the explosion at the Chernobyl Nuclear Power Plant (CNPP) is shown to contradict significantly the experimental facts available from the accident. The period of reactor runaway in the accident is shown to be unexplainable in the framework of the existing physical models of nuclear fission reactor. A hypothesis is suggested for a possible magnetic mechanism, which may be responsible for the rise-up of the reactor reactivity coefficient at the fourth power generating unit of CNPP in the course of testing the turbine generator by letting it run under its own momentum.

1. The Questions not Answered

The present paper is aimed at clarifying the physical mechanism of RBMK-1000 reactor explosion. The official conclusion does not seem to be satisfactory: First, many questions, as shown below, have not been answered; Second, the official conclusion is based on a numerical simulation whose results do not agree with the experimental facts and analytic estimations. Here a hypothesis is suggested that the accident was caused by the change, in the course of testing the turbine generator by running it under its own momentum, of decay of the nuclei emitting delayed neutrons. Despite what seems at first glance to be the low plausibility of such a hypothesis, it provides a simple and logical interpretation of the variety of experimental facts that have not been explained previously.

In the authors' opinion, a number of experimental facts observed during the Chernobyl accident have not been explained convincingly. These include:

- the integrity of structures in the reactor cavity,
- the impossibility of locating a considerable amount of fuel,
- two detonations 1–2 s apart,
- an unnatural bright glow above the reactor cavity after the explosion,

- a distortion of the isotopic ratio in the fuel samples studied, including the isotopic shift toward ^{235}U,[1,2]
- the attraction of electrical cables to steam pipes,
- and most important: the very mechanism of reactor's runaway. How could the reactor with a high rate of fuel consumption (up to 20 MW day/kg), and spoiled with xenon, be accelerated within 10 s from 200 MW power level (i.e., 6% of nominal power) to the level exceeding the nominal one by a factor of several dozen? Why did the safety rods fail to stop the runaway? According to the reactor design, the rod lowering rate was sufficient to compensate for any possible accidental runaway which, if driven by the delayed neutrons, could happen with a typical time of ∼10 s (i.e., with the lifetime of the nuclei emitting delayed neutrons). The runaway, however, proceeded three times faster. The power level of 530 MW was registered by the instruments at the third second; the sixth second brought the signal from the AZ controller which had been tuned at the 1600 MW power level. Afterwards, the runaway proceeded presumably much faster – no detailed information is available. Thus, within the first 6 s the power was increasing by a factor e each 3 s.

The above facts do not agree with the official version[3−6] in which the analysis of the origin and evolution of the accident was based on a numerical simulation. The authors of[3−6] suggested the following main sources of the accident:

- As the reactor was spoiled before the accident, the operative reactivity margin was limited to 6–8 safety rods only, with the minimal allowable number equal to 30 rods; of course, a decrease of the operative reactivity margin by itself does not lead to a runaway, but it is dangerous because it produces an unstable state.
- Development of a strong of energy release (i.e., neutron density) inhomogeneity in vertical direction in the reactor, caused by the downward motion of the safety rods, led – under the condition of the decreased operative reactivity margin – to the reactor's runaway.
- The high positive value of the steam reactivity coefficient (compared to the designers' specifications) resulted in a substantial shortening of the instability development time. The steam reactivity coefficient α_φ is defined as a ratio of the rate of excess reactivity variation to the rate of specific steam content variation in the coolant.

Let us evaluate the possibility of altering the reactor runaway time in the frame of the official accident model. The intensity of neutron breeding in the reactor core is described by the neutron-breeding coefficient K_b, which is the ratio of the neutron number of a certain generation to a similar number in the preceding generation. The excess reactivity ρ is defined as $(K_\mathrm{b}–1)/K_\mathrm{b}$. For $\rho = 0$ the reactor is in a steady-state regime, for $\rho < 0$ and $\rho > 0$ the reactor is, respectively, slowing down and accelerating. In the process of nucleus decay a small fraction β of neutrons is emitted by the daughter nuclei; they do it with a large enough delay of ∼10 s (these neutrons are called delayed). For various types of reactors the β value varies in the range from 0.2 to 0.7%. For the given RBMK-1000 (high-power channel-type reactor), before the accident the β value was equal to 0.45%. The reactor state is well known to be described by the following kinetic equations:[7]

$$\frac{\mathrm{d}n}{\mathrm{d}t} = \frac{\rho-\beta}{T}n + \sum_i \lambda_i C_i, \qquad \frac{\mathrm{d}C_i}{\mathrm{d}t} = \frac{\beta_i n}{T} - \lambda_i C_i, \tag{1}$$

where C_i, λ_i, and β_i are, respectively, the density, the inverse lifetime, and the fraction of nuclei emitting delayed ith group neutrons (β is the value averaged over all the β_i values); $T = 10^{-3}$ s is the lifetime of one generation of neutrons. For the estimation one can use the wide-spread one-group approximation for delayed neutrons, taking $\lambda = 0.1\,\mathrm{s}^{-1}$ (Ref. 7) and, hence, the condition $\lambda T \ll \beta$. For a constant value of reactivity ρ, it is not difficult to find the eigenfunctions of the linear system of differential equations, Eq. (1).

Analyzing the eigenvalues of the increment k of the respective characteristic equation, it is easy to notice that it is the presence of delayed neutrons that makes it possible to regulate the reactor operation. Indeed, for small ρ (namely, $0 < (\beta–\rho) \sim \beta$), one obtains from Eq. (1): $k = \lambda\rho/(\beta–\rho)$, i.e., the reactor speeds up with a characteristic time of ∼10 s, which is the lifetime of nuclei emitting delayed neutrons. For large values of reactivity, $\rho > \beta$, one obtains $k = (\rho–\beta)/T$, i.e., the runaway is due to instantaneous neutrons, with characteristic time less than 0.1 s. Of course, the function $k(\rho)$ is continuous for any reactivity and, for a certain ρ value, may become $k \sim 3\lambda \sim (3\,\mathrm{s})^{-1}$. In such a transient region, $\rho \leq \beta$, the function $k(\rho)$, however, goes up very fast – therefore, the phase volume of initial conditions for such a solution is small. In other words, the solution with $k \sim 3\lambda$ is unstable in the sense that for a small reactivity change as in the course of turbine generator test, this solution has to change its time increment to a substantially different value. In the accident, however, the power rise proceeded, during two periods (i.e., 6 s), with a constant increment, which obviously suggests that the observed runaway should have been a stable one.

The excess reactivity depends on parameters of the medium, including the coolant density γ. As regards the cause of the runaway, it was claimed in[3−6] that upon decrease of the coolant density one has to observe a strong rise of excess reactivity up to 5β (where β is the fraction of delayed neutrons) – see curve "a" in Fig. 1 taken from Ref. 4. The authors presented the dependence, which was calculated at the stage of design (see curve "b") and appeared to agree with the experimental results obtained in the course of testing the RBMK-1000.

It is seen that these curves differ substantially for low values of γ. The calculated curve "b" in Fig. 1 is confirmed by the results of experimental tests, whereas curve "a" is based on a single event that took place in 1986 at the fourth unit of the Chernobyl Nuclear Power Plant (CNPP). From the scientific viewpoint, curve "b" in Fig. 1 has a larger credit.

Note that for an excess reactivity $\rho > \beta$, the reactor runaway is driven by instantaneous neutrons. Therefore, the validity of the curve $\rho(\gamma)$ given in Ref. 4 would imply that the reactor may have been accelerated by merely a complete coolant withdrawal. Such a trivial disaster in water supply must lead to a runaway driven by the instantaneous neutrons with period less than 0.1 s (in such a case, the reactor turns to be an "atomic bomb"). Were it so, a further exploitation of such type reactors would be inadmissible. We hope anyway that curve "*b*" in Fig. 1 is more realistic as it was obtained by the designers who accurately and with much responsibility both calculated and experimentally tested all the main parameters of the system at various stages of fuel burning.

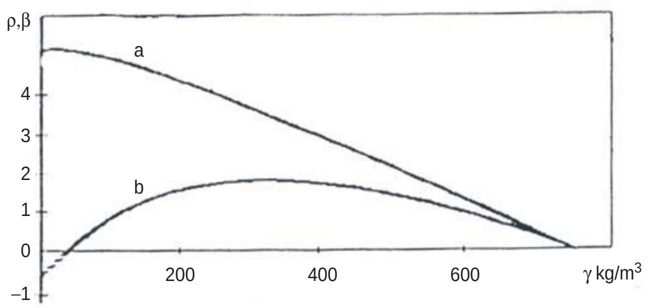

Figure 1. Excess reactivity, in the units of β, as a function of the coolant density γ: "*a*" – the calculation after the accident;[3−6] "*b*" – the design curve (i.e., the one calculated before the accident).

According to the official version,[3−6] the accident developed as follows: a localized power rise under condition of diminished level of the operative reactivity margin (6/8 safety rods instead of minimally required 30 rods) caused a localized overheating of the coolant. This resulted in a decrease of the coolant density, which, in turn, induced an increase of excess reactivity – see curve "*a*" (Fig. 1). The rise of reactivity heightened the reaction rate and the power (note that the heat release power is proportional to the neutron density) resulted in the development of instability in the time behavior of neutron density. Below, the time of such an instability development is shown to substantially exceed the actual time of the reactor runaway observed during the accident even if one takes, as input data, the disputable curve "*a*" (Fig. 1) for the dependence of the excess reactivity coefficient on the coolant density. Note that beside the steam reactivity coefficient, also the temperature and power coefficients may influence the dynamics of instability, by diminishing the rate of the reactivity rise.[8]

It has been shown[9] that the runaway of the reactor RBMK-1000 of the Chernobyl NPP fourth power-generating unit was during the accident driven by delayed neutrons. This conclusion[9] was based on the instrument readings that indicated that the power rise during the first 6 s had been developing at a constant value of the excess reactivity, $\rho \sim 0.5\beta$, and the power had changed with time approximately by the law $N = 200\,e^{t/3}$ MW, i.e., with a period of 3 s. Further on, the runaway became probably faster: after the next 4 s, a signal pointing to a sharp increase in the gas pressure in the reactor graphite stack was detected. Thus, in accordance with the available data, the runaway of the reactor power lasted on the whole $t > 10$ s. Based on this fact, it was reasonably concluded[9] that the reactor runaway had proceeded with a participation of delayed neutrons because with instantaneous neutrons the process would have been approximately 100 times as fast and absolutely uncontrolled by instruments at the control panel.

The irrelevance of the runaway driven by instantaneous neutrons is supported indirectly by the absence of visual damages of the reactor wall (the so-called casing). This fact was established in 1990 by the staff of the "Complex Expedition" of the Kurchatov Institute: drilling wells made it possible to survey the reactor's internal surface with the help of a periscope. The reactor cavity was found to be fully empty, i.e., the reactor itself had completely disappeared. No visual deformations or damages of the internal surface of the casing were observed and, moreover, even the paint coating was well preserved. Visual inspection revealed some signs of soot only in the southeast area of casing's internal surface. This cast doubt on the hypothesis of fire in the reactor and a subsequent melting of the fuel. The experts who investigated the fragments of the fuel arrived at the same conclusion.[10]

The above arguments suggest a conclusion that the scenario of the accident[3,4] widely accepted to date not only fails to explain the facts, it directly contradicts them.

2. Analysis of the Widely Accepted Mechanism

According to the official version, the rise of reactivity was caused by large steam coefficient values. In this approach, however, the rate of the reactivity rise is proportional to the neutron density, and therefore the neutron flux has to grow much slower compared with the case of a sudden change of reactivity considered in Ref. 7. We will show that even for the overestimated values of the calculated function $\rho(\gamma)$ – curve "a" in Fig. 1 – the e-times rise of the power from 200 to 530 MW would require not less than 20 s, whereas the actual rise took 3 s.

Given the validity of the overestimated version of the dependence $\rho(\gamma)$ (curve "a" in Fig. 1), one can obtain the following restriction on the steam coefficient α_φ:

$$\alpha_\varphi = \frac{d\rho}{d\gamma} < \frac{6\beta}{75\%} = 3.6 \times 10^{-4}\%^{-1},$$

because, as follows from the data[8] (page 34), in the reactor which attains the steady-state regime of fuel reload, $\beta = 0.0045$. Note that the officially reported value[3] is even smaller: $\alpha_\varphi = 2 \times 10^{-4}\%^{-1}$.

According to the reactor design,[8] the steam capacitance of the reactor with nominal power operation amounts to 1.5 T/s, while the average outlet value of γ is equal to 15% and the amount of coolant inside the reactor is not less than 30 T; the rate of the coolant density (specific steam content) variation in time is proportional to the power (i.e., to the neutron density).

The coolant is pumped through the reactor by eight Main Circulation Pumps (MCP). The schedule of the tests of the fourth CNPP power-generating unit assumed four of these pumps to be fed by the electric circuit of the 3rd CNPP unit. Therefore, these four pumps must have been sufficient for the reactor cooling at least up to 50% of nominal power, whereas the reactor runaway started from 6% of the nominal power.

Even if the coolant circulation had stopped completely, which could not have happened, the rate of the reactivity rise would not have exceeded the value:

$$\frac{\mathrm{d}\rho}{\mathrm{d}t} = \frac{\mathrm{d}\rho}{\mathrm{d}\gamma}\frac{\mathrm{d}\gamma}{\mathrm{d}t} < \frac{6\beta}{0.75}\frac{1.5\,\mathrm{T/s}}{30\,\mathrm{T}}\frac{W_0}{W_\mathrm{n}},$$

where $W_0 = 200\,\mathrm{MW}$ is the initial reactor power for the runaway process, and $W_\mathrm{n} = 3200\,\mathrm{MW}$ is the nominal power. Hence, for the maximum $\rho(t)$ growth rate, one has the equation:

$$\frac{\mathrm{d}\rho}{\mathrm{d}t} = \alpha\beta\frac{n}{n_0}, \tag{2}$$

where $\alpha < 0.025\,\mathrm{s}^{-1}$, n and n_0 are the neutron density and its initial value. Note that Eq. (2) is valid locally because we have restricted ourselves to the assumption that the coolant confined in a closed space is evaporated at the expense of released heat.

Solving the system of Eqs. (1) and (2) in the approximation of single effective group of delayed neutrons and allowing for the initial conditions $\rho(0) = 0$, ${\rho'}_\mathrm{t}(0) = \alpha\beta$, and ${\rho''}_\mathrm{tt}(0) = \alpha\beta {\mathrm{n}'}_\mathrm{t}(0) = 0$ as far as the runaway started from the steady state, we arrive at the equation:

$$\left(\frac{\mathrm{T}}{\beta}\right)\frac{\mathrm{d}^2\rho}{\mathrm{d}t^2} + \left(\frac{T\lambda}{\beta} + 1\right)\frac{\mathrm{d}\rho}{\mathrm{d}t} - \frac{\rho}{\beta}\frac{\mathrm{d}\rho}{\mathrm{d}t} - \frac{\lambda\rho^2}{2\beta} = (T\lambda + \beta)\,\alpha. \tag{3}$$

In the approximation considered here ($T\lambda \ll \beta$ and $T\alpha \ll \beta$), this equation has an exact solution:

$$\sqrt{\frac{2\alpha}{\lambda}}\mathrm{arctg}\left(\sqrt{\frac{\lambda}{2\alpha}}\frac{\rho}{\beta}\right) - \frac{\alpha}{\lambda}\ln\left(1 + \frac{\lambda}{2\alpha}\left(\frac{\rho}{\beta}\right)^2\right) = \alpha t. \tag{4}$$

For $t \ll \alpha^{-1} = 40\,\mathrm{s}$ the following approximation holds:

$$n(t) = n_0\left[1 + \alpha t + \left(\frac{3}{2}\alpha^2 + \frac{\lambda}{2}\alpha\right)t^2 + \mathrm{o}\left((\alpha t)^2\right)\right]. \tag{5}$$

Thus, in the frame of adopted initial conditions, the power rise during the first 10 s cannot significantly exceed a factor of 1.5. This agrees with the solutions[7] because in our case at the first stage the excess reactivity increases linearly at the rate α. During the accident the reactor increased its power e times each 3 s, so it follows that even the steam reactivity coefficient as high as taken in Refs. 3 and 4 (see curve "a" in Fig. 1) could not have been the cause of reactor runaway upon the coolant overheating.

The multi-group model for the description of delayed neutrons will not change major results: the $e-$times power increase from 200 to 530 MW cannot have been attained faster than within 20 s, whereas actual rise took 3 s. The numerical models suggested in Refs. 3–6 fail to explain the rate of reactor power runaway. This casts doubt on the validity of the calculated dependence of the excess reactivity on the coolant density (curve "*a*" in Fig. 1), which seems to be too high compared to the respective designed values (curve "*b*").[8]

Let us consider the statement[3] concerning the role of spatial inhomogeneity of energy release (i.e., neutron density) in the reactor runaway. First, note that the bursting depressurization of reactor and flying reactor's away apart indicated, most probably, on rather homogeneous increase of neutron density.[11] Moreover, already in the pioneering papers by Fermi,[12] the allowance for spatial inhomogeneity under condition of a small positive excess reactivity was shown to suppress high spatial harmonics. For a high enough reactivity, the high spatial harmonics grow up, at least, slower that the fundamental one. Indeed, the first equation in (1) takes, with allowing for spatial inhomogeneity, the following form Ref. 12:

$$\frac{\mathrm{d}n}{\mathrm{d}t} = D\Delta n + \frac{\rho - \beta}{T} n + \sum_i \lambda_i \mathrm{C}_i, \tag{6}$$

where $D = L^2/T$ is the coefficient of neutron diffusion, T, as above, is the lifetime of one generation of instantaneous neutrons, and L is the diffusion length. The diffusion length is $L \sim 50\,\mathrm{cm}$ for graphite and $\sim 3\,\mathrm{cm}$ for water. Seeking solutions of Eq. (6) in the form $n(t) = \varphi(x,y,z)f(t)$ under conditions $n = 0$ at the reactor boundary, we find:

$$\Delta\varphi = -q^2\varphi, \tag{7}$$

$$\frac{\mathrm{d}n}{\mathrm{d}t} = \frac{\rho - (qL)^2 - \beta}{T} n + \sum_i \lambda_i \mathrm{C}_i,$$

where q is the wave vector.

It is seen that the inhomogeneity decreases the reactivity by a value $(2\pi L/a)^2$, where a is the wavelength of spatial harmonic of the perturbation. In other words, spatial inhomogeneity of the neutron distribution gives rise to a diffusion term in the reactor kinetic equations. This term "washes out" the fluctuations of neutron spatial distribution.

We can summarize the above considerations as follows.

(1) The official versions of the accident contradict the available facts and contemporary physics at the following points.
   - The dependence of reactivity on coolant density is overestimated with respect to the designed data.
   - The increment of the instability growth calculated analytically from the equations analyzed exceeds by far – even for the overestimated reactivity – the respective results of numerical simulation.[3–6]

- The claim of a strong inhomogeneity of neutron density is not compatible with the explosion; anyway, a strong inhomogeneity may result in an increase of the runaway time rather than its decrease.

(2) The cause of the CNPP accident has not yet been convincingly explained and the contemporary state of science does not seem to be able to provide such an explanation.

(3) To interpret such a high rate of the reactor runaway, we think one should assume the existence of a new physical phenomenon (or even a number of such phenomena).

Below we suggest a possible mechanism of the reactor runaway which does not contradict the above-mentioned facts.

3. The Bound-State β-Decay

Despite the common belief that the energy-space-time scales of nuclear processes differ considerably from those of atomic ones, many examples of a strong coupling of atomic and nuclear phenomena are known to physics.

A theory of β-decay into a bound state (i.e., a decay in which the β-electron does not escape from the atom and is captured into an unoccupied bound state in the atom) was developed in Refs. 13–16. The bound-state β-decay was shown[17] to additionally increase the phase volume of final states and, hence, to increase the probability of β-decay. The ratio of the decay constants (i.e. decay probabilities) into the bound, $\lambda_{\rm b}$, and free states, λ_c , was calculated in Refs. 15 and 16. For the low energy β-decay of fully ionized heavy atoms, the ratio $\lambda_{\rm b}/\lambda_c$ can be as large as 10^3 to 10^4. Thus, the presence of unoccupied electron states may result in a thousands of times increase of β-decay probability.

The theory of the bound-state β-decay was successfully verified in experiments.[18,19] Interestingly, for ^{187}Re (Ref. 19) the complete ionization decreased the half-lifetime by a factor of 10^9 (specifically, to 33 years for a bare nucleus vs. 4.3×10^{10} years for a neutral atom).

The calculation of the ratio of probabilities of β-decay into bound and free states is similar to a conventional calculation of the ratio of probabilities of K-capture and positronic β^+-decay.[20] Relying on the results,[15,16,20] we can formulate the following significant statement:

> for every allowed nuclear transition the appearance of an unoccupied electron state in the atom increases λ, the constant of β-decay, by a value $\delta\lambda$ (in atomic units $\hbar = c = m_e = 1$):

$$\frac{\delta\lambda}{\lambda} = \frac{\pi}{2}\frac{|\Psi_e(R)|^2\,(E-1)^2}{f(Z,E)} \sim \frac{2\pi(\alpha Z)^3(E-1)^2}{N^3 f(Z,E)}, \tag{8}$$

where $\Psi_{\rm e}(R)$ is the value of the electron wave function at the point of nucleus location, E the energy of nuclear transition, Z the nuclear electric charge, and

$f(Z,E)$ is the Fermi integral function:

$$f(Z,E) = \int_1^E F(Z,\varepsilon)\varepsilon\sqrt{\varepsilon^2-1}(E-\varepsilon)^2 \mathrm{d}\varepsilon, \quad (9)$$

$\alpha = 1/137$ is the fine structure constant, and N is principal quantum number of the unoccupied state of electron in the atom. The second relation in Eq. (8) is derived within the approximation of hydrogen-like atomic state of electron. According to the well-known approximation,[20] the function $f(Z,E)$ of Eq. (9) rises with increasing energy faster than E^2 (for $E \gg 1$ one can use the approximation $f \sim E^5/30$). This enables us to find from Eq. (8) for $N = 1$ the value of $\delta\lambda$:

$$\frac{\delta\lambda}{\lambda} \sim 60\pi \left(\frac{\alpha Z}{E}\right)^3. \quad (10)$$

It is seen that $\delta\lambda/\lambda$ is larger for nuclear transitions with a lower transition energy E, i.e., for transitions to upper-lying (excited) levels in the daughter nucleus.

The β-decay to the bound state opened owing to the atom ionization was considered in Refs. 13–19. There are, however, other ways to produce unoccupied electron states. Kadomtsev[21,22] turned to the problem of transformation of electron states in an atom in a strong magnetic field. It was shown[21] that electrons, in heavy atoms in a strong magnetic field, do not tend to occupy the lowest energy levels. This means that the atom will be in an excited state and the lowest unoccupied atomic levels will be opened for the β-decay into the bound state. This implies that the application of a strong enough magnetic field opens the bound-state β-decay channel. The presence of a strong magnetic field in the accident is suggested by the observed ejection of electric cables from the wall. The probable origin of such a strong magnetic field is discussed below. We shall now turn to the problem of how the bound-state β-decay can influence the fraction of delayed neutrons in the nuclear reactor.

4. The impact of disturbed rate of decay of nuclei emitting delayed neutrons upon the reactivity

The decay of ^{235}U gives a large number of daughter nuclei of atomic weight in the range from $A = 72$ to 160. The distributions of daughter nuclei in their mass and electric charge have been investigated in the literature in detail. The majority of daughter nuclei are unstable because of an excess of neutrons.[23,24] A part of these nuclei (∼50 nuclei) are capable of emitting delayed neutrons. The scheme of their decay in which they are the mother nucleus is shown in Fig. 2.[24]

The β-decay of mother nucleus (i.e., emitter of a delayed neutron) via the channel with a lower β-transition energy gives an intermediate nucleus in an excited nuclear state. If the excitation energy exceeds Q_n (the binding energy of the neutron), the intermediate nucleus emits a neutron. This emission takes place practically instantaneously, and so the delay time is fully determined by the lifetime of the

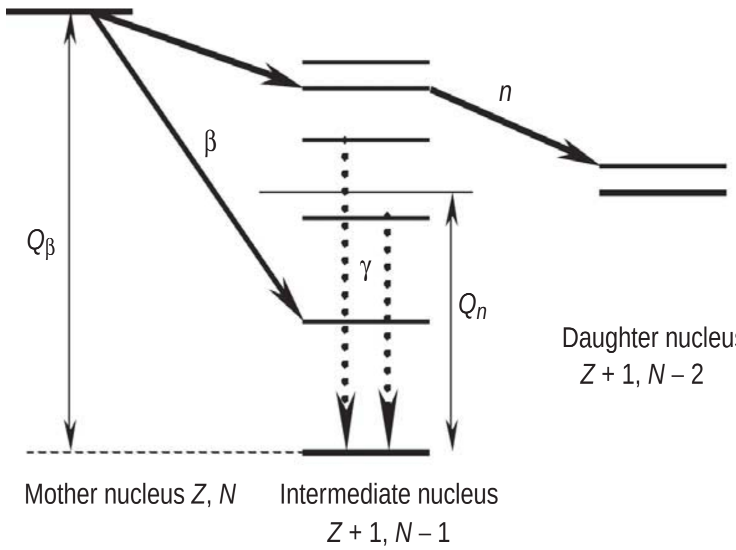

Figure 2. The scheme of decay of a nucleus emitting delayed neutron. $Q_{\rm b}$ is the maximum energy of β-decay, and $Q_{\rm n}$ is the binding energy of the neutron in the intermediate nucleus.

mother nucleus. Note that the fraction of delayed neutrons is determined by the β-decays with small transition energy, and their fraction for all the emitters of delayed neutrons does not exceed 10%.[24]

For the majority of intermediate nuclei, the energy of neutron escape amounts to the value $Q_{\rm n} \sim 5$ to 7 MeV. As far as the energy $(Q_\beta - Q_{\rm n})$ of β-decay with a neutron yield is much smaller than Q_β, it follows from Eq. (10) that if the channel of the bound-state β-decay is open, the ratio $\delta\lambda_{\rm n}/\lambda_{\rm n}$ for the neutron channel with a small energy E has to exceed considerably the value of $\delta\lambda_\beta/\lambda_\beta$ for a neutronless decay to lower-lying levels:

$$\frac{\delta\lambda_n}{\lambda_n} > \frac{\delta\lambda_\beta}{\lambda_\beta}. \tag{11}$$

The fraction of delayed neutrons is proportional to the ratio:

$$\beta \propto \frac{\lambda_{\rm n}}{\lambda_{\rm n} + \lambda_\beta}.$$

The relative change of fraction of delayed neutrons cab easily be derived to give:

$$\frac{\delta\beta}{\beta} = \frac{\lambda_\beta}{\lambda}\left(\frac{\delta\lambda_{\rm n}}{\lambda_{\rm n}} - \frac{\delta\lambda_\beta}{\lambda_\beta}\right) > 0,$$

where $\lambda = \lambda_{\rm n} + \lambda_\beta + \delta\lambda_{\rm n} + \delta\lambda_\beta$. Hence,

> the appearance of an unoccupied electron state in an atom, capable of emitting a delayed neutron, leads to an increase of the fraction of delayed neutrons.

Equation (6) allows for the densities of only those nuclei emitting delayed neutrons that underwent β-decay via the neutron channel, while the daughter nuclei which underwent the β-decay without neutron emission are thought of as lost to the chain reaction. In fact, the neutrons, which caused the production of daughter nuclei undergoing a neutronless β-decay are taken into account in the growth of the energy loss, i.e., in the decrease of the reactor excess reactivity ρ.

As is known,[24] the number of decays with neutron release is less than $\nu_{\rm n} \sim 10\%$ of the total number of β-decays of nuclei emitting delayed neutrons. In the steady-state regime of reactor operation the fraction of delayed neutrons is $\beta \sim 5 \times 10^{-3}$, the decay constant for nuclei-emitters is $\lambda \sim 0.1\,{\rm s}^{-1}$, and the lifetime of instantaneous neutrons is $T \sim 10^{-3}\,{\rm s}$; Eq. (1) gives the concentration of all the nuclei emitting delayed neutrons (including also those nuclei whose decay does not release the neutron):

$$C = \nu_{\rm n}\frac{\beta}{\lambda {\rm T}}n \sim \nu_{\rm n} 50n \sim 500n,$$

i.e., the number of nuclei emitting delayed neutrons exceeds the number of instantaneous neutrons by more than two orders of magnitude.

A huge number of daughter nuclei capable of emitting neutrons are always present in the reactor. Therefore, the distortions of the mechanism of decay of emitters of delayed neutrons may cause a considerable change of the neutron density.

To analyze the behavior of the reactor upon changes of the β-decay constant λ, we consider the kinetic Eq. (1) in the single-group approximation for delayed neutrons with allowance for all the nuclei emitting delayed neutrons (including also those nuclei whose decay does not release the neutron):

$$\frac{{\rm d}n}{{\rm d}t} = \frac{\rho - \beta}{T}n + \lambda_n C, \qquad \frac{{\rm d}C}{{\rm d}t} = \frac{\beta_t n}{T} - (\lambda_n + \lambda_\beta)C, \tag{12}$$

where n is the neutron density, ρ the excess reactivity of reactor, β the fraction of delayed neutrons, $T = 10^{-3}\,{\rm s}$ the lifetime of one generation of instantaneous neutrons, N the density of nuclei emitting delayed neutrons, including nuclei whose β-decay does not release the neutron; $\lambda_{\rm n}$ the constant of β-decay with release of neutrons, λ_β the constant of β-decay without release of neutrons, and $\beta_{\rm t} = \beta(\lambda_{\rm n} + \lambda_\beta)/\lambda_{\rm n}$ is the fraction of all the nuclei emitting delayed neutrons.

Let us consider a reactor in a steady-state regime, i.e., with reactivity $\rho = 0$, the reactivity caused by the instantaneous neutrons being constant, $\rho_{\rm inst} = -\,\beta_{\rm b}$ ($\beta_{\rm b}$ is the initial value of the fraction of delayed neutrons). Consider the variations $\lambda_\beta \to (\lambda_\beta + \delta\lambda_\beta)$ and $\lambda_{\rm n} \to (\lambda_{\rm n} + \delta\lambda_{\rm n})$ which obey Eq. (11). Assuming the above variations to occur instantaneously (i.e., in a time interval $\ll T$), we derive the following relation from Eq. (12):

$$\frac{{\rm d}^2 n}{{\rm d}t^2} + \left[\frac{\beta_b}{T} + \lambda\right]\frac{{\rm d}n}{{\rm d}t} - \frac{\beta_b}{T}n\left[\delta\lambda_n\frac{\lambda_\beta}{\lambda_n} - \delta\lambda_\beta\right] = 0 \tag{13}$$

(here $\lambda = (\lambda_n + \lambda_\beta + \delta\lambda_n + \delta\lambda_\beta)$) which, in the first order in $\delta\lambda$, describes an instability with the following increment:

$$k = \lambda_\beta \left(\frac{\delta\lambda_n}{\lambda_n} - \frac{\delta\lambda_\beta}{\lambda_\beta} \right) \left(1 + \frac{\lambda T}{\beta_b} \right)^{-1} . \tag{14}$$

As is known,[24] the major contribution to the production of delayed neutrons stems from daughter nuclei $Z \sim 35$ to 37. For the neutronless channel the transition energy is estimated to be $E_\beta \gg E_n \sim 1$ (in units of the electron rest mass). Using a rough estimate of Eq. (10) and allowing for the inequality $T\lambda \ll \beta_b$, we have:

$$k \sim \lambda \frac{\delta\lambda_n}{\lambda_n} \sim \lambda 60\pi \left(\frac{\alpha 35}{1} \right)^3 \sim \pi\lambda \sim 0.3 \text{ s}^{-1}, \tag{15}$$

i.e., in the presence of decays into bound states the time of power rise-up by a factor e may be equal to $\sim$3 s. Of course, this is a rough estimate but its coincidence with the period of reactor runaway in the accident at CNPP hardly seems to be occasional.

Thus, the following mechanism of the accident evolution is suggested: the impact of a strong magnetic field upon the reactor core may result in distortion of the electron shells around nuclei emitting delayed neutrons, with the production of unoccupied electron states close to the atomic nucleus, this makes possible the β^--decay into bound states, which results in an increase of the decay constant, $\lambda \to \lambda + \delta\lambda$, the respective relative increase of probability of neutron-releasing decays into excited nuclear states, $\delta\lambda_n/\lambda_n$, substantially exceeds the value $\delta\lambda_\beta/\lambda_\beta$ for decays without neutron release, hence, the fraction of delayed neutrons, β, increases, in an active media, this leads to the runaway of the reactor.

Thus, in contrast with the official version,[3] it is not the reactivity that increases to the value 5β (see curve “” in Fig. 1), but the value of β itself, i.e., the fraction of delayed neutrons.

5. Probable Role of Magnetic Monopole in the Accident

This brings about reasonable questions: What could be the source of magnetic monopoles at the fourth unit of the Chernobyl power plant? How could they get into the reactor? The idea of invoking magnetic charge as a mechanism of the Chernobyl accident has arisen during a study of the physical properties of the “strange” radiation observed in Ref. 25. In experiments dealing with electric discharge on metallic foils in fluids[26] for nuclear emulsions and film detectors located at distances of up to 2 m from the setup axis, abnormally broad tracks similar to a caterpillar’s track appeared regularly. Since the sizes of the tracks did not allow one to explain their origin in terms of known kinds of radiation (α, β, γ), the existence of a new type of radiation, conventionally referred to as “strange”, was assumed. When a weak magnetic field, $H_Z \sim 20$ Oe, was applied to the setup along the Z-axis, the pattern of the tracks changed. This circumstance suggested a magnetic nature for the detected radiation and provided grounds for regarding the radiation as a flux of magnetic particles.[27,28]

The current source used in the described experiments[26] was a discharge of a capacitor bank. In the tests done on April 26, 1986, the eighth turbine generator was disconnected from the substation and served as a power source for the purposes of only the fourth unit of the Chernobyl Power Plant. It is noteworthy that the initial power of the running under it's own momentum turbine generator was 40 MW and the run lasted for ∼40 s; hence, an occasional short in the electric circuit could have created conditions similar to those used in experiments in Ref. 25. This analogy is largely intuitive but it complies well with evidence given by the operating personnel.

Tregub, the supervisor of the previous shift at the fourth unit told the following. "First, I heard a characteristic noise of a shutting-down turbine generator. About 6 s later there was a stroke. I thought that the turbine blades were broken. Then another stroke followed. I looked at the upper floor and felt that it was going to fall down. I moved away to the safety shield. The instruments displayed a terrible emergency. I ran out of the building ... a floodlight shone from the "Romashka" roof but some glow was also seen above the fourth unit."[29]

Davletbayev, deputy supervisor of the turbine department said: "After several seconds, a low-pitched sound was heard from the turbine building, the floor and the walls were severely shaken, the dust and small-sized chips fell down from the ceiling, the fluorescent lighting died out, and there became darkish. A hollow stroke accompanied by thunder-like bursts was immediately heard. Then the lighting appeared again."

Dyatlov, the deputy chief engineer at the second tail of the Chernobyl Power Plant said: "I heard the first stroke from the turbine building. It was heavy but not as heavy as the next one, which was heard several seconds later. This was perceived as either one long stroke or two strokes following one another. The second one was more intensive."[30]

Thus, contrary to the generally accepted opinion, this hypothesis suggests that the development of the accident started at the turbine building and that pressing the emergency button AZ-5 incidentally coincided in time, and by no means could have prevented the disaster. The initial suggestion of the formation of magnetic monopoles at the moment of turbine generator run under its own momentum can be advanced to form some scenario of the accident development. The magnetic monopoles, which have presumably formed in the vicinity of turbine generators, could get into steam pipes. Since oxygen is paramagnetic, magnetic particles should form so-called "bound states" with oxygen and move along the steam pipes, together with the steam, as in wave-guides. A "magnetic current" should have flown in the steam pipes. The electric wires located near such a field should be attracted to the magnetic current formed by the monopoles moving along the steam pipes. This can be really observed when one passes along the steam pipe route; moreover, some of the distribution boards were torn off together with the fastening fittings and fragments of partitions (near the separator department). In the separator buildings, even the partitions were ruined. The magnetic charges, having got into the main circulation pumps should, caused a failure in the electric motor operations.

Apparently, this fact is responsible for the failure of power supply for four main circulation pumps (two north and two south ones). The failure took place exactly in those pumps that were supplied from the running under it's own momentum turbine generator No. 8. The other four main circulation pumps were supplied from the third unit and these pumps remained intact.

After entering the reactor, the magnetic monopoles should have interacted both with the ^{238}U nuclei and the nuclei emitting the delayed neutrons, which resulted in the growth of reactivity and hence, rise up of the power and the steam explosion. The probable production of a huge amount of hydrogen as resulted from nuclear transmutation may have caused a hydrogen explosion as well.

The two successive explosions in the region of the reactor at the moment of the accident[30] can be consistently explained within the framework of the mechanism we consider if one takes into account the difference between the pipeline lengths from the turbine building to the north and south separators.

Based on experimental results,[26] it can be claimed that not only ^{238}U nuclei but also some other nuclei, for example, ^{12}C, could be transformed under certain conditions under the action of magnetic monopoles. Thus, it can be suggested that once magnetic monopoles have got into the reactor, the reactor graphite should also undergo a transformation. In a study of the elemental composition of the post-accident fragments of graphite blocks from the fourth unit of the Power Plant, considerable islets of Al, Si, Na, and U were found within the graphite depth, although it is well known that highly pure graphite is used in reactors. This fact can serve as indirect evidence supporting the assumption about partial transformation of graphite.

A number of eyewitnesses including the members of the Government Commission have noted that the glow observed above the ruined reactor during the first days after the accident was unnaturally colored.[29] This fact can be easily explained within the framework of interaction of magnetic monopoles with excited atoms, which shifts the electronic levels of optical transitions,[32,33] giving rise to a color spectrum unusual for the human eye.

6. Conclusions

The author is aware of the fact that his hypothesis may provoke quite understandable skepticism among professionals. However, any hypothesis is admissible if it is able to explain some of the facts that do not fit in the framework of the existing views, and predicts some other facts that can be verified experimentally.

The following studies are proposed for verifying the hypothesis in question:

(1) A thorough determination of the isotopic composition of uranium in the fuel-containing masses (FCM).
(2) Determination of the isotopic composition of the graphite units and carbon contained in the FCM (certainly, with allowance for the conducted campaign).

(3) It is quite probable that radionuclides not characteristic of a uranium fuel cycle will be detected, because some ^{238}U should have split under the action of the monopoles.

(4) Fresh fuel assemblies were left in the central room and remained tight. If magnetic monopoles did actually participate in the accident, some of these could get into the fresh fuel and thus distort the initial isotope ratio toward ^{235}U.

(5) Finally, a direct experiment can be carried out, because magnetic monopoles should be stable particles such as electrons and one could attempt to detect them using nuclear emulsions. The tracks of magnetic charges are rather typical[26] and can be easily identified. The monopoles themselves can be "pulled out" by means of a current coil.

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