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Safety of nuclear power

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Abstract The main questions related to nuclear power development concern effects of small radiation doses typical for the operation of nuclear power plants (NPPs) and hazards of NPP accidents. The last decade has brought many results of large scale epidemiological studies indicating that there are no detrimental effects of low radiation doses. On the contrary, many results indicate that among the people receiving increased radiation doses the frequency of cancer mortality is reduced. The review shows that such results are obtained in the studies of people living in high background radiation areas, of workers exposed to ionizing radiation and of patients exposed to radiation for diagnostic purposes. The latest studies in molecular biology suggest an explanation for possible beneficial effects of low radiation doses. This is reflected in the statements of several scientific bodies and international organizations, although the official regulations remain unchanged.

The other important issue is the safety of NPPs in case of accidents. Reasons for the Chernobyl accident are shown not to be applicable to the reactors planned for Poland and the effects of Chernobyl are shown to be much smaller than feared in original estimates after the accident. Polish NPPs will satisfy the requirements of EU utilities and will provide safety for the population even in case of hypothetical severe accidents. Nevertheless, discussion with antinuclear organizations must be expected, although the recent examples of changing attitudes of leading ecological authorities show that nuclear power is gaining recognition as a clean and environmentally friendly source of energy.

Key words low radiation doses • LNT • hormesis • epidemiological studies • biological defense mechanism • Chernobyl effects

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Reduction of doses around nuclear installations

After 50 years since the foundation of the Nuclear Research Institute, Poland once more stands before the perspective of nuclear power plant (NPP) construction, this time with reactors of the 3rd generation, provided with effective safety systems. But during the past half century many questions have been asked, and they must be answered if the society is to agree to nuclear power development.

The basic question is: Are small radiation doses, typical for operation of NPPs and nuclear fuel cycle installations, dangerous for human beings?

Until the middle of XX century it had been believed that radiation doses below a certain threshold do not involve health hazards, but on the contrary – enhance human health. However, in 1959 the International Commission on Radiation Protection (ICRP) adopted the hypothesis that any dose of radiation, however small, can result in cell damages and eventually lead to cancer. This approach helped to stop nuclear weapon testing, and was reflected in the principle that radiation doses should be reduced to the values as low as reasonably achievable (ALARA). An example of the effects of this

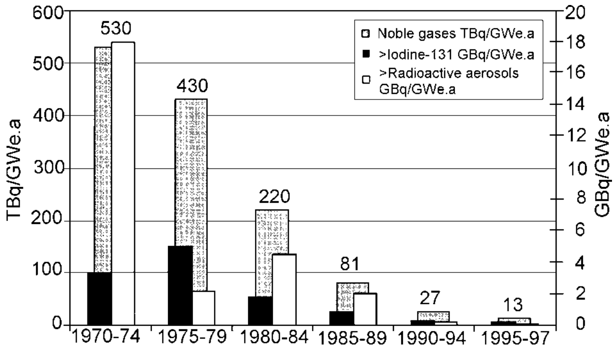

Fig. 1. PWR emissions per unit of electric energy, data from UNSCEAR [42].

approach in nuclear power is the reduction of radioactive emissions from PWR NPPs shown in Fig. 1, with data taken from the latest UNSCEAR report [42].

Currently, the emissions from NPPs are close to zero and the doses due to those emissions are many times smaller than natural variations of radiation background due to such factors as the increased height above sea level or local radon radiation. While the variations of natural radiation background are mostly from 2 to 10 mSv/year, the typical dose rates for the critical group – that is for the people most exposed, living next to the NPP – are about 0.01–0.03 mSv/year. Figure 2 presents a comparison of additional doses due to presently operating NPPs with limit dose values recommended by the European Union and ICRP, allowed by nuclear safety authorities in various countries and established as target values for new NPPs according to the European Utilities Requirements (EUR) [14].

It is seen that the utilities impose requirements which are stricter than the requirements of EU and ICRP. These requirements are being met. For example, in the case of a large NPP with an EPR reactor of 1600 MWe being built in Olkiluoto (Finland) the annual dose for the critical group will be below 0.014 mSv [39]. In comparison with the variations of natural background the doses from NPPs are negligible.

Are small radiation doses harmful?

But the belief that even very small doses of radiation can be harmful is a great psychological obstacle to the acceptance of nuclear power. This belief is based on the fact that high radiation doses are harmful. Using

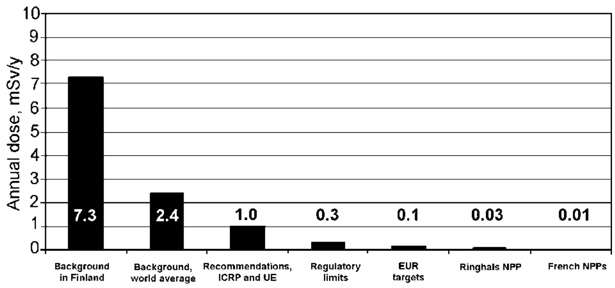

Fig. 2. Comparison of annual doses from NPPs with natural background and regulatory limits.

the precautionary principle, ICRP adopted the hypothesis that negative effects of radiation are proportional to the dose and that there is no threshold below which our organism would be able to provide effective defense against radiation. This hypothesis is called linear no-threshold (LNT) hypothesis. Following LNT, the health damage due to radiation is determined by extrapolation of health effects observed in the cohort of people who received high radiation doses at high dose rates after atomic bomb attack on Hiroshima and Nagasaki (so-called ABS cohort – atomic bomb survival) to the area of small doses down to zero. This approach, however, neglects the effects of natural biological defense mechanisms (BDM) in our organisms. These mechanisms act at various levels, namely that of the cell, of the tissue and of the organism, and their effectiveness is different at various dose rates. In particular, in the case of low radiation dose rates (when the organism has the time to react to the radiation effects) BDMs are very effective, and enhance organism defenses against other damaging factors, which are not connected with the radiation, but are due, e.g. to metabolic processes. This enhancing defense capacity of the organism can lead to hormesis – that is to positive health effects of small radiation doses.

For high doses, the damaging effects of radiation dominate the picture, therefore in the region of doses above 0.1–0.2 Sv the LNT hypothesis is true. On the other hand, many studies have shown [41] that the effects of small doses are so small as to be negligible, or show the reduction of cancerogenesis, which corresponds to hormesis (Fig. 3). Therefore, although in radiation protection the LNT is still applied, in comparative analyses it is necessary to account for the fact that the hazards of small doses are not confirmed by any studies in large human populations. Even if these effects were detrimental, they are too small to be perceivable. According to LNT supporters, the studies would have to cover millions of people and tens of years in order to get statistically significant results which would make it possible to reject or confirm the linearity of dose-effect relationship at very low doses. On the other hand, the existence of hormesis could give larger effects that would be easier to observe, and indeed studies in large human populations seem to provide support for the existence of such positive effects [41].

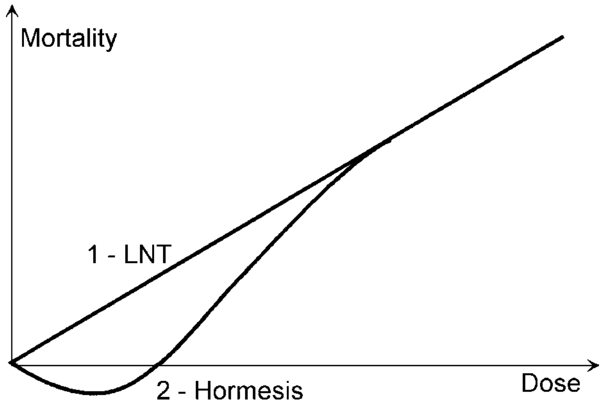

Fig. 3. Possible models of low dose effects.

The discussion about the correctness of the LNT hypothesis continues and stimulates new studies. They include epidemiological studies on large human populations and laboratory studies aimed at clarification of biological processes due to radiation effects.

Studies of inhabitants of high background radiation areas

People in high background radiation areas (HBRA) live in conditions most closely resembling those around a NPP, because they are exposed to small doses of additional radiation acting at low dose rates over many years. The difference consists only in the value of this additional radiation – around a NPP it is much more smaller than in the HBRA.

The studies of such populations have been going on for half a century. They covered scores of regions, starting from spas with radon sources such as Misasa in Japan [28], through Yangjiang province in China (dose rates about 6.4 mSv/year) [44], Kerala in India (up to 35 mSv/year) [29], or Ramsar in Iran, where the average dose rates are 10.2 mSv/year and maximum dose rates reach 260 mSv/year. Cancer mortality was not higher in any of the regions with increased radiation, but on the contrary, the results of studies in many areas suggest that the cancer mortality is lower.

Extensive studies have been repeatedly conducted in the USA, in order to find the difference between the states with low and those with high radiation backgrounds. In all cases it was found that high radiation background is accompanied by low cancer mortality. These results were obtained by scientists of impeccable honesty, completely unrelated to nuclear power industry, such as Frigerio and Stowe [16] (Quakers), Hickey [20] from Argonne National Laboratory, and in the middle of 90-ties of the XX century – prof. Bernard Cohen [7–9]. Frigerio pointed out that before his study it had been expected that in the regions of increased radiation background the cancer mortality would be much higher – but the results were exactly opposite. In his paper he describes "how it was possible for us to begin with the presumption that background radiation must be carcinogenic only to be forced (...) to conclude that it is not" [16].

The true frequency of lung cancer mortality in US states of the highest radiation background is on the average 44/year per 100,000 inhabitants, and in the states of the lowest radiation background it is 73/year per 100,000 inhabitants [34].

Among most widely quoted are the studies of the influence of radon in households on lung cancer conducted by Cohen [8], which covered 1730 administrative districts of the USA, inhabited by 90% of US population. The results showed that the increase of radon in households does not result in increased lung cancer mortality – on the contrary, the lung cancer mortality is lower in regions of higher radon radiation.

In order to eliminate the influence of confounding variables, Cohen considered those factors, that can influence lung cancer mortality, namely smoking, uncertainty about radon concentration values, influence of outliers and further 50 socio-economic indicators of various types. Cohen also analyzed the influence of geographical features, height above sea level, weather etc., but in all the trials the slope of lung cancer mortality *vs*. radon concentration remained negative. The studies of Cohen arose heated dispute and their results were attacked [17, 18, 26, 36], but Cohen successfully answered all criticisms [6, 7, 10, 11]. In particular, his opponents claimed that by averaging radon exposures over large populations he committed an error called ecologic fallacy. To understand the sense of "ecologic fallacy" let us assume that cancer occurs only after radiation exposure above 20 time the average value r_o. If in county X the average radiation exposure is 1.5 r_o, but there are no exposures above 20 r_o, while county Y has the average exposure 1.0 r_o but 1% of its population is exposed above 20 r_o, then the county Y would have a higher cancer rate even though county X has a higher average radon exposure. To state the problem succinctly, the average exposure does not determine the average risk [8].

However, if the linear no-threshold (LNT) model is right, then the average exposure does determine the average risk. Cohen explained that his study was aimed to answer the question whether LNT is right, and it is based on LNT that small doses are integrated over large populations to determine the collective dose [8, 11]. According to Cohen, his study shows clearly that the reality is different than would follow from the LNT hypothesis, so that calculating the number of hypothetical deaths due to small radiation increments in large populations is unjustified.

Other US studies have confirmed that there are no observable negative effects among large human populations exposed to low radiation dose rates [20, 34].

Studies in other world regions have also shown no observable increase of cancer mortality in high background radiation areas (HBRA). For example, in large scale studies in Yangjiang in China, where the average annual doses in the HBRA are 6.4 mSv and in the control area (CA) 2.4 mSv, it was found that the cancer mortality was

- in CA 53.5/100,000;
- in HBRA 46.3/100,000 [44].

In order to see better the results of long-time exposure to increased background radiation, cancer mortality was compared between those two regions for people aged 40 to 70 years. The result was:

- in CA 168/100,000;
- in HBRA 143.8/100,000 [44].

Thus in HBRA the increased background radiation is associated with a decreased cancer risk. The negative correlation of cancer mortality and dose rate is described by a negative coefficient ERR = –0.11, but since the confidence range in that correlation overlaps the confidence range established for ABS cohort studies, Chinese data are not statistically significant enough to show that the LNT hypothesis should be rejected [44]. There is no doubt however, that there is no observable increase of cancer mortality [43].

The studies are being continued, and in related publications Japanese and Chinese scientists state "studies conducted for many years in China give systematically results which suggest beneficial effects of ionizing radiation on human organisms" [33].

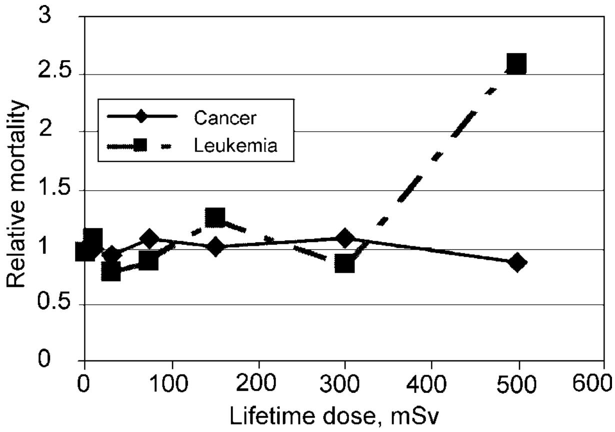

Fig. 4. Radiation effects for nuclear workers, data from [3].

The latest report of the French Academy of Science and French Academy of Medicine [1] states "cancer mortality in majority of populations exposed to low additional radiation doses is not significantly increased, and in majority of cases the data show it is decreased".

Studies of workers subject to occupational radiation exposures

The results of studies of 100,000 workers of nuclear industry in USA, Canada and UK analyzed by the International Agency of Cancer Research (IACR) show that in the region of low doses the cancer mortality does not increase, but gets lower with the increase of the dose in proportion of –7%/Sv. Relative cancer and leukemia mortality in function of cumulated dose received over lifetime by workers exposed to occupational irradiation is shown in Fig. 4, developed by the author on the basis of numerical data from [3].

It is seen that there is no increase of cancer mortality or leukemia mortality in the range up to about 300 mSv per lifetime. Then leukemia mortality increases for very high doses, of the order of 0.4 Sv. It is a good illustration of the qualitative difference between effects of low and high radiation doses. At high doses, the increase of leukemia is clearly visible. On the other hand, the low doses, such as from a nuclear power plant – that is of the order of 1 mSv over lifetime – are not connected with any health hazards. Moreover, the curves suggest that in that region there is a decreased cancer mortality.

There are many statistically significant results of epidemiological studies suggesting hormetic effects of various factors, among them ionizing radiation. According to the state of knowledge in 2005 "hormetic model of dose-effect is more widely used in toxicology than threshold model" [2]. But in spite of a very large cohort and many years of observation the results of study [3] are not sufficiently significant statistically to prove that the LNT hypothesis should be rejected. What is seen, however, is that in case of low doses obtained at low dose rates – and this is the case of NPPs – there are no negative health effects to be found.

A large study of nuclear workers in Shippingport in the US, lead by the Head of the Department of Epidemiology in a leading US University and peer reviewed by distinguished scientists at half a year intervals during the study, showed that cancer mortality among the group irradiated with low doses (above 5 mSv) was by 24% lower than in the control group consisting of workers from the same shipyard, who had not been irradiated during the work [27]. Owing to that choice of the control group from the same shipyard and doing the same kind of tasks it was possible to avoid "healthy worker effect", so that the results of the study [27] are often quoted as the proof for beneficial effects of radiation.

In connection with the suggestions that the irradiation of parents can adversely influence health of the children, National Radiological Protection Board (NRPB) in UK performed multiyear studies and in November 1997 declared: "The results of the new large epidemiological study do not agree with the thesis that the exposure of parents to radiation before child inception is the reason for leukemia and non-Hodgkin lymphoma (LNHL) of the children" [30].

In particular "No confirmation has been found for the claim of increased risk among parents who before child inception have received a dose of 100 mSv or higher, or during the 6 months before child inception a dose of 10 mSv or higher"[30].

Moreover, no connection has been found between the irradiation before inception and other categories of cancer among children [30]. The reports of UK Committee for Medical Aspects of Radiation in Environment (COMARE), both from 1994 [12] and the latest report from 2005, in which the most sensitive statistical and mathematical tools were used confirmed that "there are no indications of any increased children cancer mortality in the radius of 25 km from NPPs" [13].

Achievements in studies of biological processes after human organism irradiation

The last decade brought great progress in our understanding of biological processes which provide the defense of cells, tissues and organisms against radiation hazards. This made it possible to describe various defence mechanisms, which have variable effectiveness depending on the dose. Previously, the defenders of the LNT hypothesis claimed that both low and high radiation doses result in the same kind of DNA damage, and the cell repair mechanisms are never 100% efficient, so that some errors can remain after repair, leading eventually to cancerogenesis. Presently the French Academy of Sciences and the French Academy of Medicine state that although DNA damage in the cell is similar for low and high doses, the defense mechanisms are different [1].

In particular, at very low doses (below a few mSv) the stimulation by radiation increases the defense capacity of the organism as a whole against cell damages due to normal metabolic processes. For example, the removal of toxic agents such as reactive oxygen species (ROS) is increased, thus protecting DNA against damage. The number of ROS threatening with DNA damages is very high so that they cause about one million DNA damages/cell/day, but owing to the biological defense mechanisms the number of mutations remaining in the cell is reduced to about 1/cell/day. On the other hand, at low dose rates e.g. 1 mSv/year the number of initial radiation damages of DNA is about 0.005/cell/day [15]. Similarly as in the case of damages due to metabolic ROS, the radiation damages of DNA are repaired or removed, so that the number of final mutations due to radiation is reduced to about 0.0,000,001/cell/day, or ten million times less than from metabolic processes. Thus at small dose rates radiation is not a significant contributor to carcinogenesis. Although radiation damages include a larger fraction of double strand breaks (DSBs) which are more difficult to repair, at the background radiation level the ratio of endogenous versus radiogenic DNA DSBs is about 1000:1 [15]. The improvement of efficiency of biological defence mechanisms results in more effective prevention of mutations due to metabolic ROS, with effects far exceeding miniscule increase of cell damages by radiation [31].

At low dose rates no negative effects of radiation are perceived, because damaged cells are not repaired but die, which is the safest solution from the standpoint of the whole organism. To quote the French Academy of Sciences, "elimination of these damaged cells protects the organism against potential cancer" [1]. The repair is activated only at higher doses. At very low doses there is no repair and thus no hazard of leaving some DNA only partially repaired.

At high dose rates the efficiency of biological defense mechanisms is reduced, and the probability of cancer correspondingly increased. Thus the effects of low and high radiation dose rates are different.

According to the unanimous opinion of the French Academy of Science and the French Academy of Medicine the actual state of knowledge shows that very small radiation doses are not hazardous [1].

Changes in the approach to hazards due to very low doses

Presently, it can be stated that

– In populations subjected to long time exposure to increased radiation there have been no observations of negative health effects of low radiation doses.
– The latest studies of biological processes suggest that it is possible to explain the differences in the effects of radiation at low and high dose rates.

Analyses of recent studies indicate the necessity to change the belief that any, even the smallest radiation dose can be damaging. This in turn leads to changes in application of the notion of collective dose. Serious scientists defending the LNT hypothesis such as D. Strom [37] believe that "it can be used only after introducing some threshold value", below which small doses would not be integrated over large populations and enormous periods of time. A similar approach was proposed by the chairman of ICRP, R. Clarke [5]. According to his opinion, what should be limited is the individual dose to the most exposed member of the critical group. "If the risk of harm to the health of the most exposed individual is trivial, then the total risk is trivial – irrespective of how many people are exposed" [5].

Presently, the LNT hypothesis remains the basis of safety regulations and comparative analyses. There are gradual changes, e.g. concerning the collective dose, which had been previously calculated by integration of extremely small doses over thousands of years and billions of people. Now ICRP warns against integration over time, recommending to check only that the critical group of present generation is safe and that the critical groups in the future will not be more exposed than the people of present generation. Scientists point out the conservatism of LNT model and the lack of results of population studies which would support LNT, but the discussion is still far from final resolution.

Nevertheless, considering that the efforts of nuclear power industry aimed at dose reduction have brought very visible effects and the doses due to nuclear power are negligibly small, it can be safely stated that during normal operation nuclear power involves no hazards to people.

Reduction of hazards in the case of a nuclear accident in a NPP

So the only problem that remains is the hazard of a nuclear accident. The Chernobyl accident cannot be considered representative even for existing NPPs, because RBMK type reactors are basically different from all water moderated reactors, both these built in OECD countries and those in the Central and Eastern Europe. While in pressurized or boiling water reactors (PWRs and BWRs) partial evaporation of water results in stopping the chain reaction, in the graphite moderated RBMK in Chernobyl the evaporation of water at low power resulted in reduced neutron absorption in water, while the moderation of neutrons in graphite continued. Due to that, after loss of coolant flow the RBMK reactor was not shutdown, contrarily, its power was increasing. In addition, the faulty design of control rods contributed to sudden power increase, so that the total power of the Chernobyl reactor during the accident exceeded 1000 fold the full nominal power. Moreover, the RBMK reactor had no containment. Since its design was secret, there was no knowledge of possible course and effects of the accidents. In addition to design faults, the safety culture was missing.

Contrary to Chernobyl, the reactors in Poland will be based on the experience of 10,000 reactor-years of operation of NPPs and on their safety analyses in 30 countries of Europe, America and Asia. During the whole half a century of operation of water moderated reactors there has been no nuclear accident that would result in loss of human life or health among the staff or population.

It should be added, that although the Chernobyl accident was the worst that could happen in any NPP, its real radiological effects were much less than claimed in many pessimistic evaluations. Contrary to initial alarming claims, the early fatalities consisted of 28 deaths which occurred during the first 4 months due to radiation cancer, and 3 deaths due to other reasons, so that the total toll of early deaths was equal to 31. Over the next 10 years 14 persons among the irradiated personnel died for various reasons, which are not directly attributable to radiation exposure [24]. The expected late fatalities due to cancer and leukemia have not been observed. As confirmed by the report of UNSCEAR [42] and by the joint report of several UN organizations together with the World Health Organization [40], the only observable disease after the Chernobyl accident consisted of about 2000 cases of occult thyroid cancers, which usually do not provoke any clinic syndroms, but can be detected in case of section or ultrasonography examinations. Prof. Jaworowski stressed that their incidence in various countries is much higher, e.g. in Finland it is 2.4%, while the greatest incidence of so-called Chernobyl thyroid cancers in children under 15 years old was 0.027% in 1994 in Bryansk [24]. Many specialists [42] state that the detection of increased incidence of occult thyroid cancers is in a large part due to increased medical surveillance after the accident. On the other hand, a recent study [4] states that the relationship of these cases with iodine doses is established. In any case, the total number of deaths due to those occult thyroid cancers has been very small. It is claimed to have reached nine [38], which is much below the original pessimistic estimates.

Apart from that, there have been no significant health effects among the population. There are no signs of cancer or leukemia increase that could be due to the radiation exposure. The lack of health effects due to radiation concerns not only the population but also the emergency staff which mitigated the accident effects [42]. The increase of illnesses such diseases of endocrinological system, circulatory and gastrointestinal diseases is not related to radiation, but to the anxiety and emotional stress of the population, provoked by radiation fear. In addition, the excessive protective measures taken by local authorities such as unjustified evacuation of large groups of population from regions, in which the lifetime doses due to the accident would be a fraction of normal background radiation, destroyed social and economic structure of life of the population and resulted in many negative effects including overdependence and a belief that the government and welfare system should solve all problems [24, 40].

The necessity for the measures taken by the Soviet Union authorities after the accident has been repeatedly questioned [24, 25]. Recent WHO report entitled “Strategy of recovery” stresses the necessity to return to the normal way of life in the Chernobyl region, observes that the evacuation caused fatal economic and health conditions and appeals for the return of inhabitants to their original settlements, evacuated after the accident without good reasons [40]. The paradox of keeping the evacuated region as a “closed area” is well illustrated by comparing the radiation doses that people obtain over the lifetime (70 years) in various countries and in the Chernobyl regions of low, medium and high contamination. Figure 5 shows that the average lifetime doses in Finland are higher than the doses in Chernobyl region of high contamination (50 Ci/km^2) –

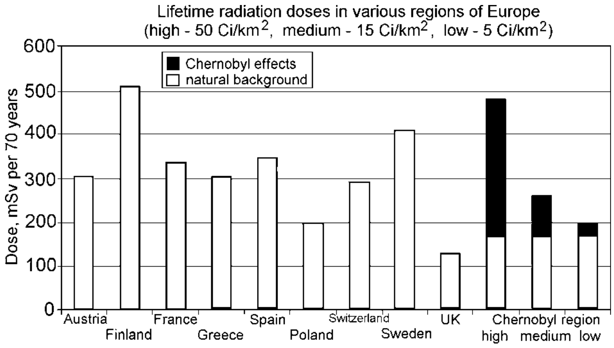

Fig. 5. Comparison of lifetime radiation doses in various countries and in Chernobyl contaminated areas.

and yet the people in Finland enjoy good health and long life (one of the longest life expectancies in the world). Needless to say, Finnish government does not intend to evacuate that country. Similarly, the lifetime doses in Yangjiang in China are higher than in the Chernobyl region with the contamination of 40 Ci/km^2, which was declared as the boundary of “closed area”, subject to strict evacuation. And as seen from the studies described above, one hundred thousand peasants in Yangjiang have good health and lower cancer morbidity than their neighbours from the region of low radiation background [44].

Although the design of reactors built in OECD countries is completely different from that of RBMK, the lessons learned in Chernobyl have been carefully studied by nuclear power industry all over the world. The Chernobyl accident stressed the need for information exchange and international cooperation regarding safety studies and upgrading of NPPs. This has contributed to the establishment of close cooperation among NPPs and among countries within the framework of international organizations such as the IAEA, WANO (World Association of Nuclear Operators) or EU. An important factor is the safety philosophy adopted in OECD, which is spreading all over the world thanks to international cooperation. As the reactor designs are accessible to all interested parties, several thousand of scientists in various countries continuously conduct safety analyses of operating and planned NPPs trying to find their faults and to propose improvements. This ensures permanent progress and upgrading of all NPPs, and provides incentives for further work.

Thus, the safety of NPPs has a very solid basis. The degree of safety already reached is illustrated in Fig. 6, based on the historical data from [21], and showing the number of early deaths occurring per unit of electrical energy produced by various energy sources. In the case of RBMKs the reference value of produced energy was taken as the total energy produced by RBMKs till the end of 1999, when the drawing was made (200 GWe-year). In the case of water moderated reactors – and such reactors will be built in Poland – the number of deaths is simply zero.

In accordance with the requirements of electrical utilities in the EU [14], nuclear safety of modern NPPs is achieved by simplification of their safety systems, by maximum utilization of natural phenomena such as gravity or natural circulation, and by incorporating the

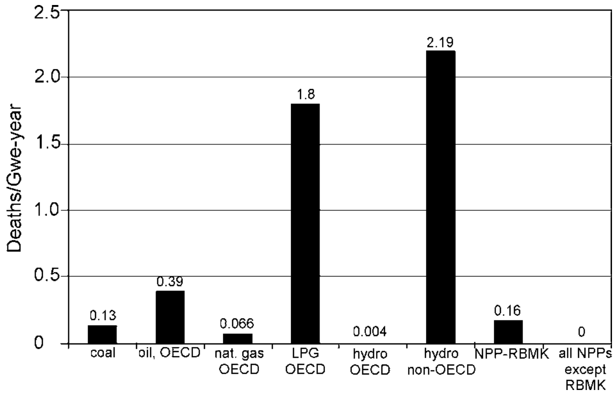

Fig. 6. Early deaths due to electricity generation from various energy sources. Data from [21].

fail-safe principle in the NPP design. The NPPs presently in operation are capable of withstanding a large range of accidents, including those that should never happen, such as an instantaneous double ended break of the largest pipe in the primary cooling system. The safety systems are designed to assure reactor safety even after such an accident, although the primary cooling system is designed with large safety margins, made of the best materials, manufactured with highest care and regularly checked by non-destructive methods throughout the reactor lifetime.

Nuclear power plants are provided with a well developed system of defense in depth, which assures safety in case of failures of safety systems and human errors, with a multiple barrier system preventing releases of fission products to the environment even in case of accidents and with containments, which keep the fission products inside the NPP and at the same time protect the reactor against attacks from outside.

In order to ensure reliable operation of safety systems, their elements are designed and tested for resistance against the maximum possible earthquakes, harsh temperatures and pressures after possible accidents and do not support burning. They are located so that neither fire not flooding can result in loosing more than one out of three or four parallel and independent trains of each safety system, one train being sufficient to provide the safety of the NPP.

In new NPPs special attention is paid to mitigation of hypothetical severe accidents. Although the safety systems and their elements are designed in such a way as to prevent severe accidents with high reliability, the designers assume that due to various reasons of very low probability the reactor core can be left without cooling and after a few hours will melt down. Therefore, beyond the safety systems typical for the existing NPPs, new NPPs are provided with a fast depressurization system to get the pressure in RCS down, to facilitate injection of water from outside sources and to prevent the danger of reactor pressure vessel break under pressure. There is also a hydrogen management system designed for hydrogen recombination or burning (to prevent the hazard of hydrogen explosion inside the containment), a reinforced and cooled foundation mat protected against melt-through in case of core melting, and finally the system of long-term containment cooling and venting, so that the containment should remain intact even in the case of a severe accident.

An NPP built to the requirements of European Utilities [14] will not require population evacuation even after a severe accident, nor will there be need to put long term restrictions on food production. Two such NPPs are being built – one in Finland, the other in France – and the plant in Poland will be as safe as those two.

Are the claims of nuclear power opponents true?

Risk is inherently involved in all fields of technology and in all human activities. Nuclear engineers are well aware of it and analyze all possible effects of accidents. Only in the case of RBMK reactors, which had a design based on military experience and fully secret, such precautions were missing. The effects of Chernobyl accident are a bitter remainder that the safety requirements cannot be neglected.

The hazards due to the Chernobyl accident have been repeatedly highlighted and exaggerated, mainly by activists of antinuclear organizations, thus getting financial means for their own activities. However, the comparisons made on the request of Swiss government by Paul Scherrer Institute showed that the hazards due to NPP operation in OECD countries are lower than for any other source of energy [22]. Studies performed in the US showed that the operation of NPPs does not increase frequency of cancer or leukemia [23]. Large studies of cancer and leukemia mortality conducted for governments of France and UK around spent fuel reprocessing plants in Sellafield and La Hague confirmed that they do not increase cancer hazards [13, 14, 19].

The false statements of antinuclear activists have been repeatedly denounced by responsible organizations of health physicists both in international community [35] and in Poland [32].

Today the public opinion supports nuclear power, and the leading representatives of ecological movements, such as Dr. J. Lovelock, who created the theory of Gaia – the Earth seen as one giant ecological organism, or Dr. Miller, one of the founders of Greenpeace express their support for nuclear power. They believe that it is the only energy source that is clean and man-friendly and at the same time can satisfy energy needs of the world. Polish ecologists also support nuclear power (see, for example, the publication of the Higher School of Ecology and Management in Warsaw [45]).

It remains to hope that other ecological organizations will be able to perceive the advantages of nuclear power and refrain from false arguments, which, while bringing them temporary financial gains, would result in long-term damages to the whole society.

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