COMPARISON OF ACCIDENT RISKS IN DIFFERENT ENERGY SYSTEMS: COMMENTS FROM RUSSIAN SPECIALISTS

An article in the IAEA Bulletin, Vol. 41, No. 1, in 1999 -- entitled "Comparison of Accident Risks in Different Energy Systems: How Acceptable?" -- has received comments through the Ministry of the Russian Federation for Atomic Energy. The comments were forwarded to the IAEA Bulletin by the Minister of Atomic Energy as a "Letter to the Editor" from L.A. Bol'shov, Correspondent Member, Russian Academy of Sciences, and Director, Nuclear Power Safety Institute of the Russian Academy of Sciences; B.A. Gabaraev, Director, Research and Development Institute of Power Engineering; L.A. Il'in, Member, Academy of Medical Science of the Russian Federation, and Director, National Research Centre-Biophysics Institute; and A.F. Tsyb, Member, Academy of Medical Science of the Russian Federation, Chairman of the Russian Scientific Commission on Radiation Protection, and Director of the Medical Research Centre of the Russian Academy of Medical Science. The comments are reprinted here along with the full list of provided references.

The authors of the IAEA Bulletin article -- Andrzej Strupczewski, former IAEA staff member of the Division of Nuclear Installation Safety and now Chairman of the Nuclear Safety Commission, Institute of Atomic Energy, Poland, and Stefan Hirschberg, Head of the Systems/Safety Analysis Section, Paul Scherrer Institute, Switzerland -- offer their response to the comments beginning on page 31.

Many articles on accident risk analysis of different energy systems in comparison with nuclear power share certain stereotypical features. For example:

- When assessing the risks associated with the operation of such facilities, they ignore the effects of the upgrading of RBMK reactors which was carried out after the Chernobyl accident.
- In their integrated assessment of the radiological consequences of the Chernobyl accident they use numerous studies which frequently contain unreliable source data and unfounded predictions, and they ignore many socio-political factors which considerably increased the damage caused by the accident.

Unfortunately, the study in question, despite its topicality and originality of approach, is also not without such shortcomings.

Upgrading of RBMK Reactors. After the Chernobyl accident, reconstruction and safety enhancement measures were implemented at nuclear power plants with RBMK reactors which were without precedent in world practice and have continued to this day. According to probabilistic safety assessments (PSA) carried out with the assistance of international experts [1, 2], the probability of serious accidents at RBMKs has decreased by a factor of two or more thanks to the above-mentioned measures.

The mean weighted safety index for all operational RBMK reactors is 10^{-4} 1/year and is decreasing thanks to the ongoing and planned reconstruction of all units. All operational nuclear power plants with RBMK reactors are thus on a par with the successfully operating Soviet WWERs and western boiling water reactors (BWRs) and pressurized water reactors (PWRs), and satisfy the IAEA recommendations regarding the risk level of older-generation nuclear power plants.

Radiological Consequences of the Chernobyl Accident. The authors of the *IAEA Bulletin* article give estimates of the remote radiological consequences of the Chernobyl accident which range from an estimated 10,000 to 30,000 fatal cases of radiation-induced cancer, and the literature on the subject contains even more extreme estimates. However, our 14 years' experience of dosimetric and medical monitoring of the population and the clean-up staff makes us somewhat critical of such estimates.

All estimates of this kind are based on a linear no-threshold model derived by linear extrapolation of the dose-effect dependence from the high-dose range to low doses. The validity of this approach is highly questionable. All the available data (extensive monitoring of tens of thousands of workers in the nuclear industries of various countries and of members of the cohort of victims of the atomic bombs dropped on Japan) suggest that there is no increase in the incidence of malignant tumours for short-term wholebody exposure levels of less than 0.1 Sv. If we take into account the attenuation of the effect under chronic exposure conditions, the level can be set at 0.2-0.5 Sv. To date there is no evidence to suggest that a measurable excess of tumours and genetic damage is possible below this practical threshold [3].

If we accept this threshold, the concept of collective dose can be ignored in practice when assessing the risk of stochastic effects in large populations from low and ultra-low doses [3].

Given the specific features of the exposure doses received by the public and the Chernobyl accident clean-up staff, and the resultant differences in the methods used to predict and assess radiological consequences, these need to be studied separately.

Radiological Consequences for the Public. During the first few years after the accident, its radiological consequences for the public were evaluated over the whole dose range, including the most contaminated areas (the so-called strict control zone where about 270,000 people were living), for the population of nine contaminated regions (15.6 million people) and the population of the European part of the USSR (74.9 million people) [4]. The study in question used highly conservative exposure dose estimates produced in 1988. These nevertheless indicated that there would be no notable increase in the mortality rate due to radiation-induced neoplasms above the spontaneous level, except for effects related to exposure of the thyroid gland. Subsequently, the estimates of the exposure doses received by the public were revised downwards to take account of the actual effectiveness of the protective measures applied. The external and internal exposure doses already actually received by people began to play an increasing role in the lifetime dose. At the same time, higher coefficients for the risk of additional mortalities began to be used in the evaluations (Publication No. 60 of the International Commission on Radiological Protection). In the 1990s, the collective dose for the 7.2 million people in the former Soviet Union living within the 37 kBq/m^2 (1 Ci/km^2) isoline was estimated at 70,000 man·Sv, and the number of hypothetical cases of fatal cancer predicted using the linear no-threshold hypothesis was calculated at approximately 3500. This figure represents 0.35% of the 1 million expected spontaneous cases of fatal cancer in this cohort [5].

According to the latest evaluations made over the 13 years following the accident, the effective doses are comparable with the total cumulative doses over the same period from natural and medical sources (> 50 mSv) only in the most heavily contaminated areas of Belarus, Russia, and Ukraine (where the caesium-137 soil contamination density is over 555 kBq/m^2 (15 Ci/km^2)). The overall number of inhabitants with cumulative doses of over 50 mSv is around 100,000. Considering that by now most of the internal and external dose has been received, the collective lifetime dose for this cohort will not exceed 7000 man·Sv. If we assume a lifetime coefficient for the risk of fatal radiogenic cancer of 5 10^{-2} Sv^{-1}, the hypothetical number of expected radiation-induced fatal neoplasms may be 350. It must be borne in mind that this evaluation relates to individual exposure doses received by the public, which are three to five times lower than the practical threshold for reliable identification of remote effects.

The vast majority of the above-mentioned 7.2 million inhabitants of the former USSR live in areas with a caesium soil contamination level of 30-70 kBq/m^2. The cumulative and predicted exposure doses for these people range from fractions of mSv to a few mSv and constitute a small fraction of overall exposure due to natural background radiation and medical procedures (4 mSv/year, of which 2.8 mSv is from natural sources, and 1.2 mSv from medical practices). In view of the above, it would be inappropriate to include this group in collective dose and risk assessment calculations.

As predicted, a few years after the Chernobyl accident there was a sharp (tenfold) increase in the number of thyroid gland disorders among those groups of the population which had received the highest exposure doses to this organ, i.e. children and youths. In the Bryansk region in Russia, for example, at the beginning of the year 2000, a total of 109 people who were children at the time of the accident had developed thyroid cancer of whom one died [6]. According to a forecast by the Russian National Medical Dosimetric Register (RNMDR), 360 cases of thyroid cancer can be expected by 2006 among the cohort of people who were children and youths at the time of the accident. The role the radiation factor plays in inducing thyroid cancer has been determined. In the case of Russia, it has only been established for people who were children at the time of the accident and only in the Bryansk Region: one-third is due to radiation exposure, while the screening effect accounts for at least 66% of the increase in thyroid cancer cases. It should be pointed out that, as more statistics are gathered, the estimates of the role played by radiation are decreasing: in earlier publications, 85% of the cancers found were attributed to radiation [7].

In fact, it has been confirmed that in all the years since the Chernobyl accident there has been no significant divergence either in the overall mortality rate or the cancer mortality rate among the population of the contaminated areas of Russia. The risk of death from malignant neoplasms, including leukoses, among the population of the Bryansk Region -- the most highly contaminated area in Russia -- both before and after the accident does not differ significantly in statistical terms from the figures for Russia as a whole.

The incidence of malignant neoplasms among the adult population of the contaminated areas in Russia is steadily increasing, as it is in the rest of Russia. However, comparisons between the pre-accident and post-accident periods, and with other areas indicate that the Chernobyl factor has had no influence on this increase [8].

Radiological Consequences for Clean-up Staff. The divergences in the predictions for the increase in cancer incidence and mortality among the clean-up staff stem basically both from the different estimates for the number of clean-up staff in different years after the accident and from the distribution of the dose burdens in these cohorts.

Currently, about 600,000 people in Belarus, Russia, and Ukraine hold clean-up staff certificates. In fact, almost three times fewer people were involved in the clean-up operations in the 30-km zone in the years when the exposure doses may have been significant for the prediction of remote effects. Doses of over 100 mSv could only have been received by some of the clean-up staff in 1986-87, of whom there were less than 250,000 in total. According to fairly conservative estimates by the RNMDR, the additional mortality which may be expected from radiogenic cancer is in the order of 1000 fatal cases (out of 250,000 clean-up staff) overall for the three countries [7]. It is important to note that all similar estimates use passport dose data, i.e. the officially confirmed external exposure dose value for each clean-up worker. Both instrumental methods and formal procedures were used to determine these.

There are also more detailed evaluations of the average individual and collective exposure doses received by clean-up staff [9-11] which take into account the way in which the dosimetric monitoring was organized in all the organizations and departments involved in the operation. According to research [11], the average doses among 117,000 clean-up staff in 1986 was 0.083 Gy, and the collective dose was 9888 man·Gy; in 1987, the figures were 0.047 Gy and 5100 man·Gy respectively. Therefore, the collective exposure dose received by clean-up staff in 1986-87 (14,900 man·Gy) may cause around 600 additional cases of fatal cancer, if we use a linear hypothesis.

Thus, a forecast of 600-1000 cases may be given for the overall number of fatal cancer cases caused by the Chernobyl accident among clean-up staff in 1986-87 in all three countries.

The years that have now elapsed since the accident mean that we can rely more heavily on the results of the medical monitoring of the clean-up staff cohort. From 1986-89, a total of 180,000 Russian clean-up staff were monitored through the RNMDR. The facts show that the overall mortality rate among clean-up staff was statistically lower than the mortality rate of the control group from the public over all the years following the accident. This can be attributed partly to the "healthy worker effect", better medical treatment, etc. No relationship between dose and mortality has been found.

We predicted an overall additional cancer mortality of 3%-4% above the spontaneous level [3, 7]. Thus, we may only speak of statistically reliable evidence of a Chernobyl-related excess in the case of rare types of malignant neoplasm (leukaemia and thyroid cancer), and only after careful epidemiological research based, in particular, on proper comparison of the effects in study and control groups.

The facts confirm this. There is no statistically significant increase in cancer incidence and mortality above the spontaneous level.

There is statistically reliable evidence for an increase in leukemia mortality among Russian clean-up staff. According to RNMDR data, 48 cases of leukoses were verified in the cohort of Russian clean-up staff for 1986-87, and one in two cases was deemed radiation-induced. It should be stressed here that the peak for radiogenic leukoses occurred four to five years after the accident [10].

Thus, the overall number of hypothetical cases of fatal cancer among the public and clean-up staff may lie between 1000 and 4500, adopting a linear no-threshold approach. This is lower than the minimum evaluation given by the authors (10,000 to 30,000 cases) in the article in question. Hence, the extent of the accident risk for RBMK reactors (in terms of fatalities/GWe·a (cf. page 27, *IAEA Bulletin*, Vol. 41, No. 1) will also be different. Applying the practical threshold for risk assessment proposed (0.1 Sv for acute exposure and 0.2-0.5 Sv for chronic exposure) would reduce these figures by a factor of 10 to 10^2.

Apart from the methodological complexities of determining the social significance of such low risks, the following must be taken into account. The cohorts in question are exposed to many other risks, including radiation risks, most of which can be significantly reduced. These factors include risks associated with medical procedures, radon in homes, chemical contamination of the environment, the quality of food products, standard of living and medical treatment.❐

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AUTHOR RESPONSE TO COMMENTS OF RUSSIAN SPECIALISTS

We thank the Russian specialists for their comments on our article. We acknowledge the progress made in reducing the risks of RBMKs and welcome the new findings on the radiological consequences of the Chernobyl accident. Nevertheless, we claim that our article is correct. Specifically,

- we note a misunderstanding about the methodology we used for the comparative assessment;
- we question the statement on the safety of all operational RBMKs being "on a par with the western BWRs and PWRs";
- we emphasize that the discrepancy between our report and the Russian assessment of the radiological consequences is due to the use of a different assumption for estimating the health consequences of low radiation doses.

For details of our analysis we refer to the original study done by the Paul Scherrer Institute (PSI) in Switzerland [1].

Study Approach. The PSI comparative study is primarily based on the evaluation of historical experience with accidents in the period 1969-96. The significant safety improvements of RBMKs that have been made do not enter into this evaluation since the PSI study (and our report) did not seek to address the *latest* level of their safety, and in any case was limited to the 1969-96 timeframe. The same rules were applied in the study's assessment of the performance of fossil systems and hydro, i.e. special credit was *not* given for the latest safety improvements that may have been implemented. For western nuclear reactors, the study employed a Level-3 Probabilistic Safety Assessment (PSA), since there is, fortunately, no actual experience at these plants with severe accidents involving fatalities. This type of PSA also was used because of the radical differences in the relevant plant designs and operational environment in comparison to the Chernobyl case and the RBMK plant. No Level-3 PSA was available for RBMKs at the time the PSI study was done, and to our knowledge none is available now. Otherwise it would definitely have been taken into account.

RBMK Safety. The core damage frequency of RBMKs has been strongly reduced from originally high levels. This is a welcome and necessary development. The few PSAs that have been performed recently for RBMKs provide useful information in identifying design and operational weaknesses and setting priorities for improvements. These PSAs, however, continue to be limited in scope concerning the initiating events of potential accidents (important external events are not fully addressed) and because they do not consider low power and shutdown states of reactor operation. Additionally, there are large differences between the Ignalina and Leningrad nuclear power plants both in terms of the estimated core damage frequency and the degree of the actual implementation of safety improvements.

Although the RBMK accident localization system, especially of the third generation units, has been further improved, RBMK plants still have no complete containment as LWRs do. This holds corresponding implications for the probability of large releases of radioactivity in the case of core damage. RBMKs also are not equipped with a fully independent secondary shutdown system. Thus, the generic statement that RBMKs "are on par with western BWRs and PWRs" is from our perspective at least questionable.

Radiological Consequences of the Chernobyl Accident. Our estimate of 9,000 to 33,000 latent fatal cancer cases was primarily based on the EC/IAEA/WHO evaluation [2] and on the findings of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) [3]. Our work was further supported by the literature review covering about 140 references, including numerous papers by Russian authors. In our article, we emphasized that the estimate is conservative.

The Russian specialists, according to their comments, arrive at an estimate between 1000 and 4500, i.e. one order of magnitude lower than ours. The Russian specialists indicate that no increase of delayed cancers has been observed and that the mortality of clean-up workers is lower than that of the general population. These statements, coming from the competent authorities in Russian radiation medicine, are very important. The specialists also emphasize that in general there is no evidence of a measurable excess of tumors or of genetic damage below the dose of 0.1 Sv for acute exposures and 0.2 Sv for chronic exposures.

We agree with these statements and support the conclusion that introduction of a "practical threshold" to dose calculations would greatly reduce the estimated potential health effects of the accident. However, the evaluation given in our paper was based on the application of the linear non-threshold (LNT) hypothesis. This hypothesis, despite its conservative character, is the basis recommended by such competent organizations as International Commission on Radiological Protection (ICRP).

The LNT hypothesis is not followed in the estimates provided by the Russian specialists for both the lower and upper limits they provided. The approach used by the Russian specialists does not take into account contributions to individual exposures below 50 mSv. This omission means that they do not account for potential health effects among evacuees; parts of the population in the strictly controlled zone; 6.8 million people in the former USSR who lived in contaminated areas; emergency workers in 1988-90; and the population of the entire northern hemisphere, which received small radiation doses after the accident.

In the EC/IAEA/WHO evaluation's upper estimate of latent fatal cancers, 23,000 of the total estimate of 33,000 cases arise within the northern hemisphere population group. The PSI study notes that the number of estimated fatalities would be significantly reduced under the assumption of a threshold for the individual dose of 50 mSv per year or of a lifetime dose of 0.1 Sv.

Thus, the main discrepancy between the EC/IAEA/WHO evaluation and the comments provided by the Russian specialists does not stem from estimates of exposures. Rather they stem from the approach -- the Russian specialists do not take into account radiation doses comparable to those received during a lifetime due to medical practices or exposure to high background radiation, whereas the EC/IAEA/WHO evaluation and PSI study do take them into account. *The Russian approach, based on a threshold hypothesis, may be right, and we personally think it is reasonable to apply it for providing the best estimates.*

However, our report in the *IAEA Bulletin* was based on the EC/IAEA/WHO evaluation. It followed the LNT hypothesis and provided a conservative upper bound of latent fatal cancers consistent with general assumptions within comparative studies of energy systems.

In summary, we view the reaction of the Russian experts not as a challenge to our paper and its overall conclusions, but rather as an opportunity for greater professional dialogue on the rationale of the LNT approach. This issue goes far beyond the estimation of the number of potential fatalities that might be attributed to the Chernobyl accident, and has a bearing on the debate over the future of nuclear power.❐

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For readers with access to the Internet, the author's article on comparative risk analysis is accessible on the IAEA Bulletin pages of the Agency's WorldAtom Web site at www.iaea.org. See the site's Periodicals Section.
The article's specific Web address is www.iaea.org./worldatom/Periodicals/Bulletin/Bull411/index.html.