FACTA UNIVERSITATIS
Series: **Physics, Chemistry and Technology** Vol. 4, N° 1, 2006, pp. 121 - 132

RADIATION PROTECTION IN THE WORLD AND IN FORMER YUGOSLAVIA AND SERBIA AND MONTENEGRO SINCE DISCOVERING OF THE X-RAYS TO NOWADAYS

UDC 53+504.055

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Abstract. *Harmful effects of radiation and call for protection against it were recognized practically immidiatly upon the discovery of X-rays and radioactivity. A chronological review of some key events in development of radiation protection is given in this paper. First, the main activities of the ICRP since its establishment to nowadays are presented. Afterwards, a general description of some, according to the author's opinion, important events in the field of radiation protection in the former Yugoslavia and Serbia and Montenegro are given as: Vinča accident; Organization of Radiation Protection Laboratory in Vinča Institute; International Vinča Dosimetry Experiment; First Symposium and organization of the Yugoslav Radiation Protection Association; the French - Yugoslav Colloquium on radiation protection; International inter-comparison experiment on nuclear accident dosimetry, and the International Summer Schools and Symposium on Radiation Protection organized in Yugoslavia. Some comments on the Three Mile Island and Chernobyl accidents are given as well. Bioindicators of low dose and dose intensity exposure are cited as one of the main problems that have to be resolved in radiation protection in the near future. Finally, as one of the main problems that, according to the author's opinion, physicists have to resolve in this field in the near future would be development of the operational dosimeter for high energy neutrons.*

Key words: *radiation protection, Vinca accident, international dosimetry experiment, inter-comparison experiment, first Yugoslav symposium, international summer schools, nuclear power plants accident*

INTRODUCTION

Harmful effects of radiation and call for protection against it were recognized rather early, practically immediately upon the discovery of X-rays (1). The warnings of Nikola Tesla and Wolfram Fuchs illustrate this statement. In June 1896, Nikola Tesla, a scientist

Received July 27, 2007

of the Yugoslav origin who worked in the USA, provided one of the earliest and, at the same time, one of the most fundamental principles of radiation protection: "Experimenters should not get too close to the X-ray tube" (2). On December 12, 1896 an article written by Wolfram Fuchs appeared in the Western Electrician, a US journal, in which simple recommendations were given on how to reduce radiation hazards (3). There were also many other examples pointing out the need for radiation protection. Still, in the first thirty years of radiation, roentgens and radium use, radiation protection was the task performed by those dealing with it in their everyday practice only - in other words, it was not regulated. Radiation protection regulation, at international level, was related to the foundation of the International Commission on Radiological Protection, i.e., its predecessor.

THE VINČA ACCIDENT

Development of radiation protection or, more precisely, the policy on how to resolve radiation protection problems is tightly connected with the nuclear-fission reactors construction. The first nuclear reactor in Yugoslavia, a zero-power research reactor, known as the RB reactor, was designed at the Vinča Institute of Nuclear Sciences and put into operation in May 1958. Unfortunately, only six months upon the event, an accident took place on October 15, 1958 (4). Shortly afterwards, the accident was registered in literature as 'the Vinča accident'. Six young persons, students and technicians, were exposed to radiation doses of about 2 to 4.5 Gy, as estimated later. One of the victims, Života Vranić, an advanced student of physics at the Faculty of Science, Belgrade University, who had carried out an experiment for his graduation thesis, died one month after the accident in a Curie hospital in Paris, after his bone marrow was transplanted during the medical treatment.

An analysis of the accident, but not from the technical point of view which can be found in literature (6), shows that one of the reasons for the serious consequences was lack of proper radiation protection measures at the reactor. It can be claimed, not particularly wise today, that if those responsible for running the RB reactor had known Enrico Fermi's approach to radiation protection from 1942, the heavy irradiation of the experimenters with fatal consequences, if not the very accident, would have been avoided.

RADIATION PROTECTION AT THE VINČA INSTITUTE

Use of radiation sources at the Vinča Institute dates back to the end of 1947, a few months before the Institute was officially opened (7). The main sources were radium and its daughters and neutron sources based on them. Later on, from 1952 to 1954, linear accelerator facilities were installed. Use of radiation sources in Serbia and Yugoslavia however dates from the time before Word War 2 and was related to the use of roentgens and radium for medical purposes. Radiation protection problems, learned from experience of others, were recognized here, too. But, at that time before and after the War and before the accident at the Institute, our approach to these problems was rather unprofessional. They were resolved by medical doctors and scientists in their attempts to protect themselves and others in the vicinity while dealing with the sources in their everyday practice. Therefore, the protection against radiation, they were undoubtedly exposed to, was not their primary task.

The Institute management realized after the accident at the RB reactor that the radiation protection should be considered more seriously. So, in April 1959 (7), only six months after the accident, the Management Board appointed a group of young researchers (physicists, chemists and others: P.S.Bojović, B. Pendić, P. Mirić, and A. Matijašić) from different laboratories of the Institute, which were given a task to deal with radiation protection solely. This group of researchers and their coworkers founded later on a new laboratory called the *Radiological Protection Laboratory*. It was a bold stroke Chicago in 1942. The reason for such an important decision was, beside the accident, a new, more powerful research reactor of 6.5 MW, the preparations for its start-up were almost completed. The Yugoslav government reacted also by adopting a law, in a cut short procedure, *The Law on Ionizing Radiation Protection* (8). So, the protection measures at a professional level became a legal obligation. At that time, Yugoslavia was one of the rare developing countries who had regulated legally the use of radiation sources.

Here, I have to point out the importance and the necessity for a professional approach to radiation protection problems. Such an approach, to my opinion, should not be limited to radiation protection only. It should include protection from all kinds of harmful agents, presence of which human senses cannot detect, or if they detect them, the reaction that follows is often too tardy.

Professional attitude towards harmful-agents protection means that those dealing with it must be out of all technological processes, products of which are agents the protection is needed from. This first demand is, unfortunately, often neglected even in the field of radiation protection. Such cases are when 'professionals' in radiation protection become involved in technologies based on radiation sources, due to commercial reasons. Then, the radiation protection problems are frequently pushed aside in favor of profit.

Professional approach to radiation protection is lacking even in some fields, where radiation sources are used, such as medicine, and not only in our country. It is the case with the medical institutions (clinic centers, larger hospital complexes, etc) where numerous radiation sources have been used extensively. Radiology physicists or medical doctors - radiologists in these institutions are usually dealing with the radiation protection, but it is not their primary activity.

The Radiation Protection Laboratory of the Vinča Institute adopted, *forty six years ago upon its foundation*, a comprehensive professional approach to radiation protection problems which has been carried out in their research, development and everyday routine activities since then. Only some key events important for the development of radiation protection in our country, the choice made by the author, will be discussed under the following subheadings: International Vinča Dosimetry Experiment, First Symposium and Yugoslav Radiation Protection Society, International Summer Schools on Radiation Protection in Yugoslavia, International Inter-comparison Experiment on Nuclear Accident Dosimetry, the Three Mile and Chernobyl Accidents, International Symposium on Radiation Protection on the Occasion of the 30th Anniversary of Radiation Protection at Vinča.

INTERNATIONAL DOSIMETRY EXPERIMENT AT THE RB REACTOR

The Vinča accident, as already said, drew attention of scientists from all over the world especially those dealing with radiation protection. The key problem after the accident was how to estimate individual doses received by the irradiated victims. For the purpose, an international dosimetry experiment was conceived under the auspices of the International Atomic Energy Agency. The aim was to simulate the accident and to determine as accurately as possible the individual doses. For the purpose, phantoms were made, equipped with at that time available dosimeters and radiation detectors, and placed at positions taken by the irradiated victims during the accident.

The dosimetry experiment coordinated by the IAEA was performed by scientists from France, the United States, Great Britain and Yugoslavia (Vinča) at the end of April 1960. The IEAE and the Yugoslav Nuclear Energy Commission signed an agreement on conducting the experiment in Vienna on February 2, 1960. According to the document, the Yugoslav government agreed to place the reactor, available equipment, buildings, services, research and other staff at the IAEA disposal. The French Nuclear Energy Commission undertook the task to reconstruct and upgrade the running and control system of the reactor, to put it into operation, and to provide its proper functioning during the experiment. The UK Atomic Energy Commission agreed to provide 6.5 tons of heavy water and all the necessary expert assistance. The United States agreed to appoint an expert group from the Oak Ridge National Laboratory to carry out the experiment, using their own equipment, and to analyze and process the data later on.

Table 1. Estimated individual doses received during the Vinča accident, given in Gy (9)

Person	Neutron dose		External γ dose	"Integral dose"**
	(n,p)	(n,γ)		
V*	0,89	1,33	2,14	4,36
M	0,87	1,30	2,09	4,26
D	0,91	1,36	1,92	4,19
G	0,90	1,35	1,89	4,14
H	0,66	0,99	1,58	3,23
B	0,45	0,67	0,95	2,07

*Family name initial

**Author's Note. The total dose absorbed was calculated as a sum of neutron and gamma dose, although these values are not additive - the reason why the total dose is in quote marks. Conversion of the absorbed doses into equivalent ones and then their summing would be more accurate. The authors, however, did not make it for the neutron weight factors for acute irradiation were unknown then, and are unknown even today. Generally, they are estimated to be a few times lower that those for chronic irradiation.

Table 1, sums up the final results of the experiment given as estimated partial and total radiation doses six young workers were exposed to during the accident. The total error is + 15 %. This was one of the first international dosimetry experiments in which Yugoslavia played, due to accidental circumstances, a significant role. At the same time it was an opportunity for the IAEA to gain reputation in the field of radiation protection.

Among foreign scientists and experts, partakers in the experiment, *Professor Karl Z. Morgan* played a key role as a leader of the Oak Ridge dosimetry group. From that moment till the end of his professional career, a period of about 20 years, Professor Morgan was always ready to help his Yugoslav colleagues, whenever asked. He was an outstanding scientist, highly respected all over the world. His contribution to the foundation and development of radiation protection as a separate scientific field was enormous. Dr.

Henry Jammet is to be mentioned here too. He was a member of a French group of doctors who accepted and medically treated the irradiated persons in Paris. Dr. Jammet was one of the leading world scientists who actively took part in framing modern radiation protection concepts summed up in the ICRP Recommendations from 1977 and 1990. He participated in almost all significant international manifestations in the field of radiation protection held in our country, and remained a valuable friend of Yugoslavia and his colleagues till his sudden death in 1996 during his trip to Libya.

FIRST YUGOSLAV SYMPOSIUM AND FOUNDATION OF THE YUGOSLAV RADIATION SOCIETY

Activities in the radiation protection field in Yugoslavia diversified greatly in the beginning of the 60s. Only some four years after the adoption of the protection policy its first professional conditions were fulfilled for the organization of an expert meeting – a symposium. The presence of all three Academies of Sciences – the Yugoslav, Slovenian and Serbian Academy among the organizers shows the importance of this current problem. The Symposium was held in Portorož on October 8-12, 1963. Although the first in a series, 20 held by now in this field, it was surely the most attended meeting. 315 participants took part (16), more than twice as much compared to the symposia held later on, and 163 contributions out of about 200 registered were presented (15). A broad interest in radiation protection between the East and the West can explain this great number of attendees. The Symposium Program included plenary sessions with general topics and three parallel sessions on Radiation Protection in Medicine and Biology, Technical Radiation Protection, and Environmental Radiation. The Symposium Proceedings was not issued but the Book of Abstracts was (11).

During the Symposium*, on October 2, 1963, the Yugoslav Radiation Protection Society was founded* and a temporary administrative body with Gruica Žarković, Toma Tasovac, Zoran Djukić, Milovan Vidmar, Petar Mirić, Dušan Stojanović, Dušan Srdoč, Velimir Popović and some others, as members, elected. It was a year before the IRPA and some nine years after the USA Health Physics Society were established.

INTERNATIONAL SUMMER SCHOOLS ON RADIATION PROTECTION IN OUR COUNTRY

In the mid-'60s there was a great need, at international level, for a more intensive, effective and faster exchange of knowledge in many fields of sciences and in radiation protection too - a need for the spoken word. Meetings known as "summer schools" played a very important role. Stimulated by the idea, a group of participants in the International Radiation Protection Colloquium held in Herceg Novi (Yugoslavia) in 1966: Ljubomir Barbarić, Predrag S. Bojović and the author of this paper, decided during one of the Colloquium breaks to initiate organization of international radiation protection schools in Yugoslavia. It must be admitted that the idea was not immediately accepted when presented to the Management Board of the Radiation Protection Laboratory of the Vinča Institute, a few days upon their arrival from Herceg Novi. It was thought that the Laboratory had not yet acquired the proper reputation in the field, and that the staff was not ready to accept and perform such a task. Even the initiators agreed with the remarks. However, they did not give up the idea bearing in mind an elementary truth: remarkable achievements can not be reached by avoiding the tasks, which at that moment seem too difficult or even unfeasible. And so, the Vinča Radiation Protection Laboratory succeeded in organizing, in the period from 1970 to 1979, four summer schools in Yugoslavia with the following topics:

- Radiation Dosimetry, Cavtat, 1970 (12),
- Protection of Nuclear Facilities Surroundings, Herceg Novi, 1973 (Proceedings not published),
- Current Problems and Concerns of Health Physicists, Herceg Novi, 1976 (13),
- Waste Disposal and other Problems in the Nuclear Industry, Dubrovnik, 1979 (14).

The most eminent radiation protection scientists (ten or more of them at each school) such as K.Z. Morgan, W.S. Snyder, N.G. Gusev, Bo Lindel, H. Jammet, D. Beninson, and others, took part and delivered their lectures. It is interesting to note that, during the third school, D.H. Sliney and R.T. Ham, from the USA, gave lectures on the danger and protection against non-ionizing radiation. Practically this was one of the first serious approaches to this problem ever expressed at an international level. The number of participants varied from 80 to 90. Forty percent of them were foreigners. Proceedings from all, except the second school, were published. The participants had a chance to hear detailed reviews of the newest achievements in the field of radiation protection presented by the famous radiation protection scientists and experts from all over the world. As an illustration, Professor K.Z. Morgan talked about the reduction in the recommended maximum permissible dose for professionals, mentioning 2R as a possible new value. 20 years later, this value was adopted at the international level.

INTERNATIONAL INTERCOMPARISON EXPERIMENT ON NUCLEAR ACCIDENT DOSIMETRY AT THE RB REACTOR

International Atomic Energy Agency (IAEA) conceived within its radiation-protection activities an international coordinated-research program on nuclear accident dosimetry in 1969. Within the framework of the program, four international multi-laboratories inter-comparison experiments were organized. The third, organized by the IAEA in collaboration with the Yugoslav Government, was performed at the Vinča Institute and its RB reactor on May 14-25, 1973 (15). The RB reactor was not chosen by chance. On the contrary, it was a remembrance of the Vinča accident and the previous dosimetry experiment carried out in 1960. In order to perform the experiment, a few large-scale adjustments of the reactor and its systems were made such as:

- extension of the control-regulation system range so that the reactor can be started up and operate in a steady mode with powers three order of magnitude higher than the nominal ones which rarely exceeded several watts,
- reinforcement of the protection screens especially those facing the reactor control panel,
- adjustment to the reactor support construction, i.e., building of an additional platform at the reactor tank bottom level with irradiation position space to accommodate a variety of dosimeters during the experiment, and
- carrying out the preliminary dosimetry measurements to characterize the radiation field, especially determination the expected neutron and gamma-ray doses and spectra.

All the adjustments, except neutron measurements, were made by the Nuclear Energy and Radiation Protection Laboratory staff of the Vinca Institute. Standardization of the neutron field was made in cooperation with the colleagues from France (16).

The inter-comparison experiment, in which about 40 experimenters from 12 countries divided into 18 groups took part, was successfully performed. Two separate irradiation experiments at the declared reactor powers of 1.05 and 6.7 kW were run for 30 min each. Data analysis and processing is given in (15) and will not be discussed here.

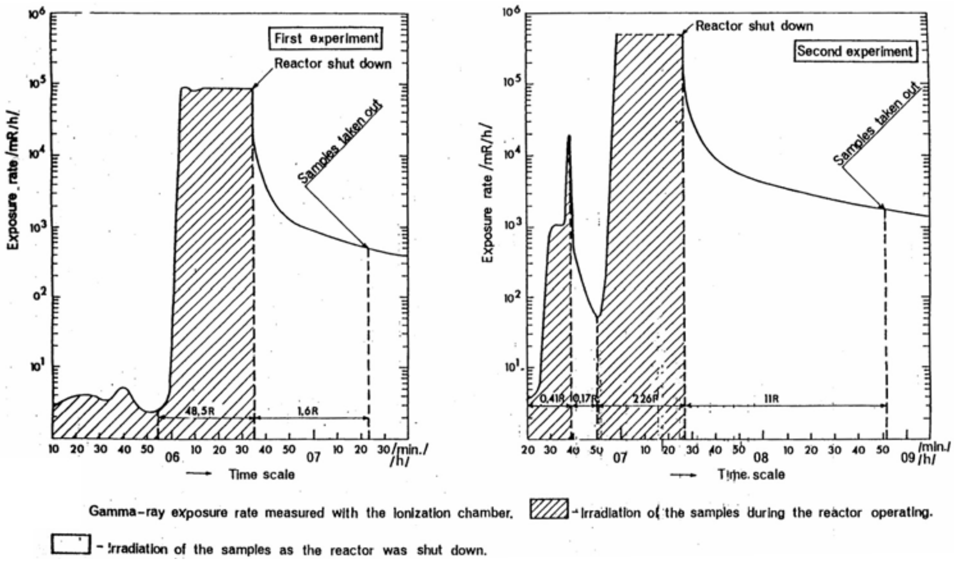

Fig. 1. Exposure dose intensity, measured by a KAKTUS ionization chamber, during Inter-comparison experiments at the RB reactor.

It is interesting to note, an observation from the radiation protection point of view, that the reactor operated for the purpose under irregular conditions which, compared with the standard regime conditions, were unavoidably accompanied by much greater risks. Being aware of that, the radiation protection operational personnel installed an additional dosimetry channel with an ionization chamber as a sensor, exclusively for their own needs. The aim was to measure continuously and independently, off the reactor measuring system, the evolution in the gamma radiation level from the reactor start-up, operation at given powers and its shut-down to the removal of irradiated dosimeters from their positions. The results of these measurements are given in Fig. 1. The data were also used to determine an integral exposure dose the dosimeters were exposed to during the experiments.

From the radiation-protection point of view, the experiment in general was conducted without any difficulties. However, a subsequent analysis revealed a discrepancy in the correlation of the reactor declared powers and the measured integral doses of gamma rays and neutrons, which means that the reactor had operated during the experiment at powers about 2.5 times higher than the reported (17). This fact is insignificant for the experiment itself, for its aim was not to make a power-dose correlation. It is also insignificant for the radiation protection, for the protection measures taken corresponded to the measured dose intensities and not to the reactor powers. This detail, however, shows that in spite of all careful preparations and adjustments of the reactor systems to operate at higher powers, an omission not so small was made. The error occurred in the reactor power control-system calibration. Everything else, except this 'detail' functioned faultlessly.

FIRST SERIOUS NUCLEAR PLANT ACCIDENTS

Rapid growth of nuclear power plants industry during the 1970s, as a direct result of an oil crisis in the beginning of the 70s, suffered severely from the first serious nuclear accident in Three Mile Island power plant in USA.

On Wednesday March 28, 1979 at 04.36 AM a few water pumps in the nuclear power plant Three Mile Island Unit No 2, located about 20 km southeast from Harrisburg, Pennsylvania failed to function (18). That is how the first serious accident in the world began. In the following minutes, hours and days, a series of events took place due to shortage of equipment, inappropriate actions, human errors and ignorance, producing a crisis in the expanding nuclear industry. Luckily, due to a combination of incidental circumstances, the accident was terminated without heavy consequences to environment, causing only a great damage to the plant (over a billion dollars as estimated). But, it had a very strong impact on further nuclear energy development. As a consequence, a vigorous anti-nuclear campaign was launched in the States and then all over the world, strongly supported by the classical power plants industry financially endangered by fast nuclear energy development. The accident also seriously shook up and led to critical views on the existing concepts of safety and protection, based on risks and probabilities. These concepts formulated in the well-known Rasmussen Report (19) were accepted as the basic planning criteria all over the world. The essence of these nuclear facility accidents, divided into 10 categories according to emergency levels, are acceptable providing that the probability of their occurrence decreases proportionally with the seriousness of the expected consequences due to applied technical and other safety and protection measures.

The next accident, much more serious than the Three Mile Island one, took place at Chernobyl on April 26, 1986 at 01.26 AM (20). This accident by its character, size and consequences exceeded all theoretically predicted accidents on such facilities. Unfortunately, it was an unplanned but also destroyed some fundamental assumptions of the existing safety theories, on the basis of which hundreds of nuclear plants all over the world had been built. According to the known hypothesis, only the areas around nuclear reactors up to a maximum distance of about 100 km were expected to be endangered even in the most serious accidents. The emergency projects were made adequately with all the safety measures foreseen and planned. But, the Chernobyl accident caused radiation contamination of the whole north hemisphere. About hundred million people, from the developed countries, found themselves suddenly in a totally unexpected situation. The simplest action levels for intervention against contaminated food became under the circumstances a great problem. They were invented in a great hurry and without much coordination between the neighboring countries. A rather chaotic situation lasted for a few days after the accident. Thousands of pages have been written about the Chernobyl accident and its consequences. Certainly the most complete information on the event can be found in the Proceedings of the Symposium on One Decade after Chernobyl held four years ago in Vienna (21). This accident will surely draw attention of the scientists in the field of radiation protection in the following fifty or more years. It can therefore be compared with the Hiroshima and Nagasaki disaster. What is important to emphasize here is an irretrievable disappearance of the classical phase as we may call it in nuclear energy with the Chernobyl accident. Consequently, all developed countries in the world, except those from the Far East, abandoned planning or building or even closed down the facilities in operation.

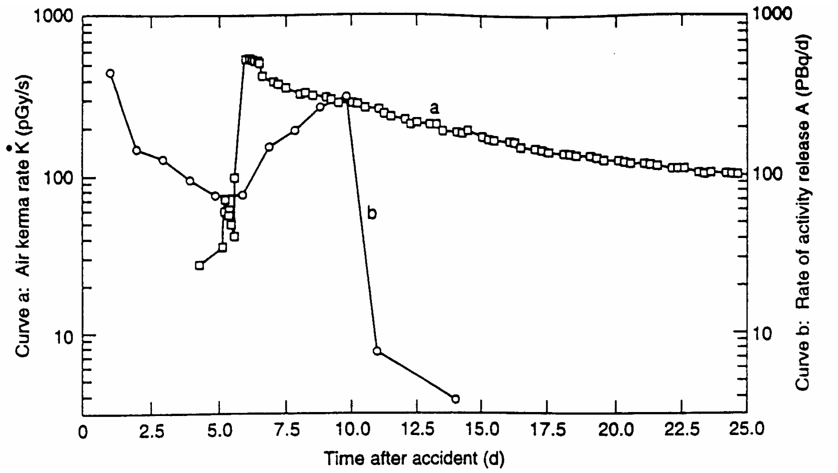

Fig. 2. Measurements of the air kerma rate (curve a), made at the reference point located at the Vinca Institute and activity release rate (curve b), during the active phase of the Chernobyl accident (24).

A new era in nuclear energy, supported today by the so-called nuclear lobbies only, still cannot be seen on the horizon, but according to some great world thinkers (22) it is unavoidable if the future development of civilization is to be in harmony with the nature. When it appears, then the new nuclear facilities will be built on the basis of new deterministic safety concepts. Future reactors must be inherently safe and 'intelligent' (23).

The chaos reigning in the world after the Chernobyl accident did not spare us in Yugoslavia, as already well known. Despite all kinds of difficulties, continuous standard measurements of the gamma rays level over Belgrade region, via air kerma rate, during the active and post-accident phase were made. The results are illustrated in Fig. 2. (24). A detailed analysis of the data given in the figure reveals dramatic moments in radiation contamination of the region in days immediately after the accident. The data were of great importance and help at that time. They were essential for the Yugoslav Radiation Protection Commission in permanent emergency session to issue proper operative measures and recommendations.

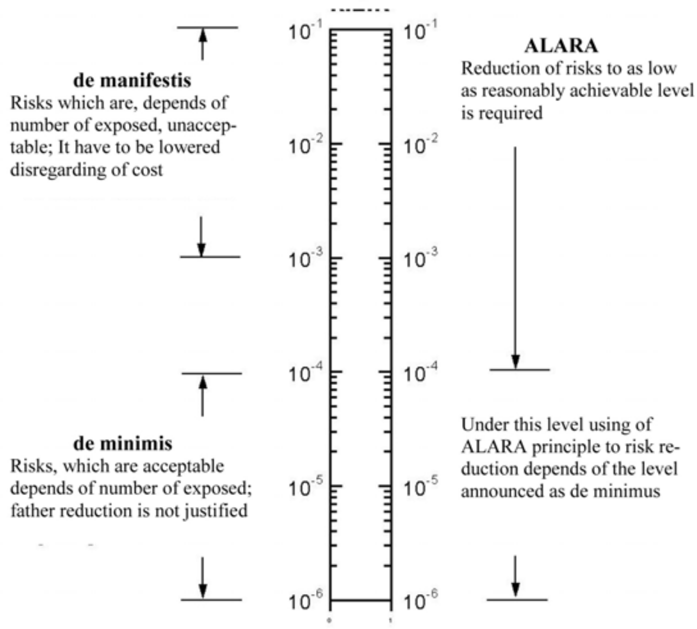

Fig. 3. Reference Risk Levels

INTERNATIONAL SYMPOSIUM ON RADIATION PROTECTION ON THE OCCASION OF THE 30TH ANNIVERSARY OF RADIATION PROTECTION AT THE VINCA INSTITUTE

Following the summer school tradition, Radiation Protection Laboratory of the Vinca Institute decided, at author's suggestion, to organize on the occasion of the 30th anniversary of its foundation an International Symposium on Radiation Protection – Selected Topics (25). Preparations for the Symposium started three years earlier. The aim was to bring together eminent scientists in the field as invited guests. The success was worth the effort. The Symposium was held in Dubrovnik in October 1989. About 150 participants attended the meeting. 111 papers were presented – 44 of them from abroad. 10 introductory lectures were given by: P. Christensen and L. Botter-Jansen from Denmark, H. Krause and J. Erhardt from the West Germany, W. Kraus and B. Dorschel from the East Germany, J.A. Bond from Canada, M. Delpla from France, and I. Ivanov and A.A. Bikov from USSR. Unfortunately, this was the last symposium for one of the most eminent Russian scientists in the field of radiation protection, in dosimetry, Igor Ivanov. Although seriously ill and under proton therapy treatment, he kept his promise made earlier to attend the Symposium. He came to Dubrovnik and delivered his lecture. He died six months later in Moscow in February 1990.

Parallel with the Symposium, an international exhibition of dosimeters and other radiation protection equipment produced by both domestic and world famous companies from Europe and North America was organized. It was the largest exhibition of the equipment staged in former Yugoslavia.

CONCLUSION

Starting from the fact that the protection of an individual is of primary importance, one of the main tasks in radiation protection today is to determine as accurately as possible the level of the real risk an individual - a professional is exposed to during his work. To achieve this, systematic and reliable recording and assessment of the individual radiation doses have to be performed. To our regret all the physics methods today used for the purpose cannot give a definitive result. Data on the internal and external exposure levels, obtained by these methods, can deviate considerably from the real exposure levels depending on the conditions, type and characteristics of the radiation an individual is exposed to. Biological indicators – biomarkers and bio-dosimeters can provide a straight answer to this question. But, bio-dosimeters, which are to register low-level radiation doses or low dose-intensities significant in the radiation protection, have not been invented yet. This is one of the key problems the current radiation protection is facing with. Qualitative development of this field of science depends, to a great extent, on a successful solution of this problem, which remains to be solved in the 21st century.

Acknowledgments. *The author gratefully acknowledge the financial support from the Ministry of Science and Environmental Protection, Republic of Serbia, through the Project No. 2016 Physics of Radiation Protection.*

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ZAŠTITA OD ZRAČENJA U SVETU I BIVŠOJ JUGOSLAVIJI I SRBIJI I CRNOJ GORI OD OTKRIĆA X – ZRAČENJA DO DANAS

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Štetno dejstvo jonizujućeg zračenja i potreba za zaštitom uočeni su neposredno po otkriću X-zračenja i radioaktivnosti. Hronološki prikaz ključnih događaja u razvoju zaštite od zračenja izložen je u ovome radu. Najpre, obrađene su osnovne aktivnosti ICRP od osnivanja do danas. Zatim sledi prikaz, po mišljenju autora, ključnih događaja na području zaštite od zračenja u bivšoj Jugoslaviji i Srbiji i Crnoj Gori, kao što su: Akcident u Vinči; Osnivanje Laboratorije za zaštitu od zračenja u Institutu Vinča; Međunarodni dozimetriski eksperiment u Vinči; Prvi simpozijum i osnivanje Jugoslovenskog društva za zaštitu od zračenja; Francusko – Jugoslovenski kolokvijum na temu zaštite od zračenja; Međunarodni interkomparacioni eksperiment akcidentalnih dozimetara u Vinči i, Međunarodne letnje škole i Simpozijum zaštite od zračenja organizovani u Jugoslaviji. Kratki prikazi i ocene akcidenata na Ostrvu tri milje i Černobilju su takođe, dati. Bioindikatori malih doza i intenziteta doza navedeni su kao osnovni problem koji treba da bude razrešen u zaštiti od zračenja u budućnosti. Konačno, kao primer jednog od osnovnih problema u oblasti zaštite od zračenja koji stoji pred fizičarima jeste, po mišljenju autora, razvoj i konstrukcija operativnog dozimetra za neutrone viših energija.