TOWARDS BUILDING NUCLEAR COMPETENCE OF RADIATION PROTECTION SPECIALISTS

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Abstract. The content of core nuclear knowledge and some methodical tools to deliver it to the radiation protection specialists is considered. The importance of some core ideas is emphasized. The role of basic nuclear knowledge in several practical cases is demonstrated.

INTRODUCTION

There are several resolutions [1-4] issued by General Conference of IAEA since September, 2000 and related to the education and training in nuclear and radiation protection. These decisions have launched the strengthening of IAEA support towards organization and management of different education and training courses and putting this policy into systematic way. Particularly, during few last years a giant pool of training materials related to numerous training courses in radiation protection and safe use of radiation sources was produced by IAEA. Almost each of them contains quotations from the nuclear science to provide trainees by the core nuclear physics knowledge sufficient for clear understanding as origination of ionizing radiations as well as its impact on substance. The main tendency of this training material is the utmost simplification of the knowledge using very rough and even not valid models of an atom and a nucleus, origination of radioactivity like Rutherford-Bohr model, equality of proton and neutron masses, etc. In some of training packages the neutrino in beta-decay reactions is omitted. Even taking into account that this material is designated mostly to practitioners who will not develop conceptual matters of the subject and there is a lack of time within the course schedule to deliver more concise knowledge, it is very important, however, to provide trainees by conceptually closed material. It is important because radiation protection specialists should understand clearly, for example, why beta spectra are broad, why the half life time of radioactive substance is constant for each kind of a nucleus, etc. to avoid rough expert mistakes when estimating some projects.

To build more competence among non-physicists involved in radiation protection and radiation use structures the non-traditional curriculum for teaching basics in nuclear physics is developed in International Sakharov Environmental University, ISEU (Minsk, Belarus) for students of university and IAEA PGEC course. The purpose of this paper is to share with specialists by methodical approach to the basic nuclear knowledge applied in ISEU.

WHAT SHOULD A RADIOLOGIST KNOW FROM FUNDAMENTALS

There are only a few of fundamental physical laws regulating the life of particles and their interaction by fields to be remembered by a radiologist independently on his/her occupational duties. They, perhaps, are:

1. A radiologist should know types of ionizing radiation, what are the differences between them and, so called, non-ionizing radiation.
2. A radiologist should understand the ionizing radiation origin and ways to get it.
3. A radiologist should understand basic effects of ionizing radiation in matter in dependence on energy and kind of radiation.

Basing on that a radiologist

- can understand in which way the doze concept takes into account these effects.
- can be able to learn about biological effects of ionizing radiation and how they contribute to a doze (absorbed, effective, committed etc.).

– has an opportunity to introduce in basics of equipment functioning.

– can understand the nature of radiation protection regulations established and can obtain a background to be able to improve them (expert level).

Knowledge of that can be considered as a core practical one for every radiologist.

The *conceptual basis of core knowledge* detailed above imply a very few of fundamental principles and consequences of fundamental laws to be assumed. They are:

1. Every micro event is happening according to conservation laws and with its own probability. The probability is one of quantitative characteristics of the event to derive a ‘value of influence’ or a probability of appearance of the effect.
2. There are three kinds of forces important at the micro level and considered separately (for current radiation protection purposes only, except, may be, some events in high energy physics experiments): hard, electromagnetic and weak. Each kind of forces or some combination of their action is responsible for definite type of ionizing radiation production. The most part of reasons have electromagnetic nature. It follows from the band of action of different kind of forces and their peculiarities.
3. An atom is almost empty. That is why neutral particles penetrate much more in substance that the charged ones.
4. The total ionization (each primarily neutral atom or molecule gives not less that one electron) is very hard because of very strong electromagnetic interaction. It is may be confirmed by simple estimation using the Coulomb law.

BUILDING A CURRICULUM

To provide an opportunity for students to gain this knowledge the following curriculum in studying fundamentals can be offered (Table I). The proposed duration of training events given in the Table I should be considered as minimum one regarding to capability to deliver the knowledge. For the sake of more deep knowledge and to avoid a formal assumption of it the duration can be expanded. From the table one may find that there is major attention to the practical exercises for solving problems in radioactivity and nuclear reactions. Four hours for radioactivity should comprise deriving connection between mean life-time and decay constant, simple methods to determine decay constant from observations, considering problems with radioactive chains and cases of equilibrium. The same problems should also be considered at experimental level including measuring radioactive background and counting statistics. In case of other nuclear reactions practical and laboratory exercises are important, at least, to demonstrate or simulate major nuclear events contributing usually into impact of ionizing radiation to matter, and, of course, to develop basic skills in solving the simplest problems of elastic and some cases of inelastic scattering of particles using as non-relativistic (nuclear reactions, as a rule) as well as relativistic (Compton-effect, etc.) expressions of energy and momentum in conservation laws.

The knowledge of basic quantum principles, uncertainly, allow to understand how to manage some solicit problems. The knowledge of action radii of fundamental forces, estimation of potential energy of atomic interactions in substance in comparison with energies of photons and other particles caused ionization give clear understanding of many practical things, partially, why half-life time of radioactive nuclei can not be influenced (in large scale) by external factors. It is shortly discussed in section 4 of the paper.

Table I. Possible curriculum contributing to the Review of fundamentals from nuclear physics.

No	Content	Total duration*	Kinds of lessons		
			Lect.[1]	Lab.[2]	Pract.[3]
1.	Quantum principles and major concepts 1.1. Probability of phenomena 1.2. Energy levels and shells 1.3. Quantum transitions. Probability of transition per unit time. 1.4. Basics of relativity. Rest energy concept. 1.5. Physical quantities and conservation laws	4	2	-	2
2.	Particles and fields 2.1. Fundamental structure of matter 2.2. Fundamental interactions. 2.3. Leptons and hadrons 2.4. Diagram approach 2.5. Confinement and asymptotical freedom	2	2	-	-
3.	Building matter 3.1. Building nuclei 3.2. Building atoms and molecules 3.3. Building substance 3.4. Stability of quantum systems 3.5. Scales and bands of physical quantities 3.5.1. Times, lengths, energies, etc. 3.5.2. Scale of electromagnetic waves	2	2	-	-
4.	Radioactivity 4.1. Radioactive decay. Modes 4.2. Gamma-radiation of nuclei 4.3. Radioactive decay law. 4.4. Chains of radioactive elements. Transient and secular equilibrium 4.5. Natural chains.	12	4	4	4
No	Content	Total duration*	Kinds of lessons		
			Lect.[1]	Lab.[2]	Pract.[3]
5.	Other nuclear reactions 5.1. Reactions going through	20	4	8	8

	a compound nucleus 5.2. Reactions with charged particles 5.3. Reactions caused by photons 5.4. Reactions with neutrons. Fission. Fundamentals of nuclear fuel cycle 5.5. Fusion 5.6. Other reactions (production of pions and other mesons, modes of their decay, annihilation, etc.)				

Is given in academic hours. 1 academic hour is equal to 40 min.

[1] Lect. – lectures.

[2] Lab. – laboratory exercises and demonstrations.

[3] Pract. – practical exercises that comprise solving problems, case studies and seminars.

The separate problem is to explain the sense of the law of attenuation of the narrow beam to give a background to understand radiation protection calculations and techniques. It can be related to the topic on interaction of ionizing radiation with mater and is not related to the nuclear knowledge properly. That is why it is not shown in the Tab. 1. But derivation of connection between mean-free-path length and attenuation coefficient is equal to the same procedure of derivation of the relationship between mean life-time and decay constant. That is why the last topic gains the specific attention.

In lectures on beta decay the special attention should be paid to the role of neutrino. Broad electron spectra and existence of maximum energy of electrons can not be explained without the neutrino concept. It is also important to explain appearance of two kinds of neutrino in decay of pions. It can be based only after delivering the part 2 of Table I. Some knowledge about pi-mesons is important for radiologists because they are produced by energetic protons from cosmic rays and in some therapeutic procedures.

Unfortunately, there is a lack of time for lessons anticipated by the Standard Syllabus of Post-Graduate Educational Training Course on Radiation Protection and Safe Use of Radiation Sources, Ref. [5]. For studying of the whole Part I "Review of fundamentals" only 1 week is anticipated. At the same time the total duration of training events presented in Table I is 40 hours of auditorium work. It is more than the least duration for one week lessons usually allowed in any university round the world. At the same time topics listed in Tab. 1 cover, at least, only the third part of the Part I of the Syllabus, Ref. [5]. Therefore, the total duration of the PGEC should be expanded. The total duration of PGEC this year in Minsk will be 21 week and there are 3 weeks anticipated to deliver the core knowledge from the Part I of the Syllabus, Ref. [5].

"UNCERTAIN" APPLICATIONS

Importance of assuming the core nuclear knowledge described above can be demonstrated by the following cases from practice.

1. There was a period of time when some officials from radiation protection authorities in Belarus were seriously considering proposals to diminish contamination of areas polluted by Chernobyl radionuclides by virtue of chemicals or using neutron generators. Only interference of specialists prevented from taking decision to subsidize money to research on that. That is why the special time in lecturing at educational courses should take the proof why decay constant can not be really changed by an external influence except nuclear reactions and what consequences will happen in soils and plants after action of neutron beam with high flux density (basic of neutron activation analysis).

2. At one of the conferences devoted to the centenary of Becquerel discovery of radioactivity held in London one of solicitors had required from scientists presented at the conference to process clear way to proof that a worker of nuclear power plant got a leukemia because of extreme radiation during his/her work. But in case of implementing all radiation protection standards and even in many of emergency situations the exposure can lead only to stochastic effects. For such cases there is the only way to insure risks to get leukemia and other diseases may be caused by ionizing radiation. These risks can be rather thoroughly calculated now.
3. Sometimes radiation protection specialists fall in doubt to which kind of radioactive waste spent fire indicators should be referred. From one hand, there are long life-time radionuclides used in fire indicators. And from this point of view they should be referred to the higher category of danger. But, from the other hand, the most important in this case is the fact that since the time of commission fire indicators contain radionuclides at the exemption level of concentration. The only important issue is do not concentrate spent fire indicators in dangerous amounts at radioactive waste disposal. The intellectual problem is to make difference between exemption level and long life-time criteria. If a radiation protection officer remember the simple expression for activity A of a radionuclide
$A = N/\tau$,
where N is the amount of radioactive nuclei ant the moment of observation and τ is the mean life-time he/she can conclude that than τ is more than the activity is lower. And it becomes clear that the argument of long life time lead only to the lower activities at the same concentrations.
Thus, the simple fundamental knowledge from nuclear physics can be applied in practice of radiation protection specialists.
SIMPLE METHODICAL TOOLS
Usually practicians do not like to make simple calculations using fundamental laws. To facilitate them choose of units of physical quantities is very important. One of the most simple calculations is met when one would like to find energy E of a photon in electron-volts (1 eV = = $1.602 \cdot 10^{-19}$ J) from its wavelength λ

$$E = \frac{hc}{\lambda}, \qquad (1)$$

where h is the Plank's constant, c is the electromagnetic constant. It is easy to remember that the product hc in units of eV·m is equal to $1.24 \cdot 10^{-6}$ eV·m. It allows making calculations with the formula (1) almost orally. For example, the energy of the ultraviolet photon of 200 nm wavelength is 6.2 eV. At the same time the photon with wavelength 1 Å = 0.1 nm (dimension of an atom) has the energy of 12.4 keV when the photon with wavelength 100 fm (approximately 10 dimensions of a nucleus) has the energy 12.4 MeV. This simple oral calculation facilitate the understanding the energy scales of events happening in the world of atoms and nuclei.

The other example is intended to simplify calculations for reactions of non-relativistic particles. The kinetic energy K for non-relativistic particle is expressed by the formula $K = mu^2/2$ where m is the mass of a particle, u is its velocity. From this formula the expression for velocity can be obtained:

$$u = \sqrt{\frac{2K}{m}}\,. \qquad (2)$$

But in case of microscopic particles expression of mass in usual units is not easy and requires using handbooks. But simple multiplication of the numerator and denominator of the fraction under the square root in (2) on c^2 lead to the expression

$$u = c\sqrt{\frac{2K}{E_0}}\,. \qquad (3)$$

where E_0 is a particle rest energy. Expressing it in eV and using eV as a measure of kinetic energy K one can make calculations easily. Non-relativistic cases are restricted by the inequality $K << E_0$. It should be taken into account while applying the formula (3). For example, the rest energy of an electron is estimated by the value of 0.5 MeV. That is why for the speed of non-relativistic electrons one obtains from (3) the following working formula

$$u = 2c\sqrt{K}\cdot 10^{-3} \qquad (4)$$

where K should be expressed in eV. This formula can be easily used in practical calculations. For instance, thermal free electrons in a metal have average energy of 0.025 eV (at room temperature). That is why their speed can be almost orally calculated from (4): $u = 2c\sqrt{25\cdot 10^{-3}}\cdot 10^{-3} = 10^{-4}\sqrt{10}c \approx 3\cdot 10^{-4}c \sim 10^5\,\text{m/s}$. This value can demonstrate the complexity of events happening with an electron in a peace of metal taking into account that the drift energy of electrons in electric current is usually of 1 mm/s.

The other example giving the feeling of simplicity of calculations within the proposed approach is calculation of speed of neutrons. The rest mass of neutrons is estimated by the value of 1 GeV, so the working formula for estimation of the speed of neutrons (and protons too) is the following:

$$u = 2c\sqrt{5K}\cdot 10^{-4} \approx 4.5c\sqrt{K}\cdot 10^{-4} \qquad (5)$$

where K is still expressed in eV. For example, for thermal neutrons the value of neutron speed is calculated like for thermal electrons and is $u \sim 7\cdot 10^{-5}c \sim 2\cdot 10^3\,\text{m/s}$. Such easy calculations provide the opportunity to understand that a neutron with so high speed can leave the reactor zone easily and only multiple collisions with nuclei of the fuel can prevent it. It gives also the opportunity to understand why reactors are powerful sources of neutrons.

To make calculation of speed of a nucleus it should be taken into account that rest energy of a nucleus in eV can be estimated through the value of its mass number A. The value of 1 a.m.u (atomic mass unit) is equal to 931.5 MeV of rest energy that can be estimated like for neutrons also by 1 GeV. That is why for estimations the formula (5) should be corrected on factor $1/A$ under the square root:

$$u \approx 4.5c\sqrt{\frac{K}{A}}\cdot 10^{-4}$$

Several examples given above show the opportunity to facilitate calculations when appropriate units are used. It is especially important to give trainees simple tools to make estimations for events important in radiation protection or for understanding radiation sources functioning.

CONCLUSIONS

To build real competence in radiation protection the meaning of sound conceptual nuclear knowledge can not be overestimated. To deliver this knowledge in rather short time restricted by a training course duration it is important to use methodical instruments to simplify understanding. The core place in it is to operate by values correspondent to the world of atoms and nuclei and expressing the real scale of events might be happened. Assuming basic quantum ideas allow to understand that in some cases insurance is the best way to solicit people when radiation leads only to statistical effects. Basic principles of nuclear physics facilitate understanding how to apply Basic Safety Standards, Ref. [6], and national requirements and provide an opportunity to develop them in accordance with principles of

BSS towards to building sustainable national and international radiation protection infrastructure.

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