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A bibliographical review on the concept of biological effects of ionizing radiation in Brazilian publications

Gonçalves[a] G.de L., Delgado[a] J. U., Razuck[a] F. B.

[a] *Institute of Radiation Protection and Dosimetry, 2278-127, Rio de Janeiro, Brazil*

fernandor@ird.gov.br

ABSTRACT

At the end of the nineteenth century, with the use of ionizing radiation for the benefit of humanity in various sectors of society, its effects on human health became evident. In this way, it is necessary to clarify the population about the main aspects related to the ionizing radiation applications, in order to better understand the concepts regarding their effects on health. And one of its main effects, within the area of radiological protection and medical physics, is called by Biological Effects. This is because ionizing radiations, due to their energy range, have the property of interacting with matter, and can alter the structure of cells by ionizing their atoms. Once it reaches the cells, ionizing radiation can produce damage, especially in DNA. This may occur either by the action of the radiation itself (direct mechanism) or by toxic radicals formed by the hydrolysis (indirect mechanism). These effects, over time, were identified and described, mainly from situations in which an individual was acutely exposed (by accidents or medical use). In this sense, this paper proposes a bibliographic review of some concepts and definitions found in the literature on Biological Effects, mainly in Brazilian publications. With the purpose of not presenting a definitive theoretical model, but rather demonstrating the range of existing concepts, the objective of this paper is generating a debate about the variety aspects that may be related to the subject, reaffirming the importance of the topic for the area of radiation protection.

Keywords: **biological effects, ionizing radiation, bibliographic review, Brazilian publications.**

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1. INTRODUCTION

1.1. Presentation

At the end of the nineteenth century, since the discovery of X-rays in 1895, ionizing radiation has been applied in many sectors of society, such as medicine, industry, construction, engineering and research. Although the use of ionizing radiation has many benefits in various sectors of society, its undesirable effects on human health have also become evident. In this way, it is necessary to clarify the population about the main aspects related to the ionizing radiation applications, in order to better understand the concepts regarding their effects on health [1].

And one of its main effects, within the area of radiological protection and medical physics, is called by Biological Effects. This is because ionizing radiations, due to their energy range, have the property of interacting with matter, and can alter the structure of cells by ionizing their atoms [1].

Once it reaches the cells, ionizing radiation can produce damage, especially in DNA. This may occur either by the action of the radiation itself (direct mechanism) or by toxic radicals formed by the hydrolysis (indirect mechanism). These effects, over time, were identified and described, mainly from situations in which an individual was exposed acutely, either due to occupational exposure (related to occupational workers, called by workers occupationally exposed to ionizing radiation – such as doctors, for example) or public exposure (as medical patients exposed to radiation or due to some kind of accident, which affects the public in general) [1].

1.2. Justification

The interest in this review is due to the fact that the theme "Biological Effects" is addressed in the Postgraduate Educational Course in Radiation Protection and the Safety of Radiation Sources (PGEC), offered by the Institute of Radiation Protection and Dosimetry (IRD) in partnership with the International Atomic Energy Agency (IAEA) [1; 2].

The PGEC is a comprehensive training program that helps to build a sound basis in radiation protection and the safety of radiation sources. Featuring both theoretical and practical training elements, the PGEC conveys the multidisciplinary scientific and technical foundation of international radiation protection standards and recommendations [1;2].

Participants are expected to be future senior managers, experts or trainers. The PGEC is hosted by the IAEA's regional training centers in Africa (training language: English and French), Europe (English and Russian), Latin America (Spanish and Portuguese) and Asia (Arabic and English) [2].

In Brazil, the course is offered at the IRD, which is the Regional Training Center (RTC) for participants from Portuguese-speaking countries. Divided into 13 parts, the course offers theoretical and practical lessons, including a specific part on Biological Effects of Ionizing Radiation. This part lasts for 20 hours/class [1-3].

In addition, the PGEC is ruled by a specific program, Syllabus, which is periodically edited and made available by the IAEA to the course directors, who for its referral to the coordinators of parties. In addition, the IAEA also offers power point classes [3].

2. **MATERIALS AND METHODS**

In this sense, this paper proposes a bibliographic review of some concepts and definitions found in the literature about Biological Effects, mainly in Brazilian publications, in the last 5 years. This review addresses the topic in different areas of knowledge, with the main objective of demonstrating the wide range of existing definitions, without the obligation or ambition to present a final concept.

Thus, the definitions will be presented according to the area of knowledge and indicated if they are related to occupational or public exposure. Thus, it is expected to generate a debate on the various aspects that may be related to the subject, reaffirming the importance of the theme for the area of radiation protection.

3. **RESULTS AND DISCUSSION**

Definitions were found in works related to seven (7) areas of knowledge or research, as will be presented below: Teaching, Dentistry, Industrial, Interventional Medicine, Medical for Emergency, Non-Radiologist Medical Physicians, Nursing and Radiation Physics.

3.1. Teaching (PGEC Syllabus)

The PGEC, as already presented in the introduction, is hosted by the IAEA's regional training centers (in Brazil is located at IRD) and is ruled by a specific program, Syllabus, which is periodically edited and made available by the IAEA to the course directors, who for its referral to the coordinators of parties [3].

Thus, according to Syllabus, Biological Effects of Ionizing Radiation appears in Part III of the document. The suggested class time is 30 hours, the main objective of which would be:

> To provide the students with an awareness of theeffects of radiation at the molecular and cellularlevels and an understanding of the tissue reactionsthat can result in stochastic and deterministic healtheffects. They will be introduced to the models usedfor estimating risk coefficients for stochastic effects [3, p.7].

In this way, the content is divided into 4 modules:

• III.1. Effects of radiation at the molecular and the cellular level (Review of cell biology; Effects of radiation on cells; Phases of damage and modifying factors);

• III.2. Deterministic[1] Effects (Effects of high doses);

• III.3. Stochastic[2] somatic effects (Tumorigenesis, also oncogenesis or carcinogenesis; Dose-response relationship);

• III.4. Stochastic hereditary effects (Hereditary effects);

• III.5. Effects on the embryo and fetus (Radiation effects);

• III.6. Epidemiological studies and issues (Epidemiological studies); and

• III.7. The concept of radiation detriment.

All this content was elaborated from a specific bibliography [4-11].

It is observed, through Syllabus, a concern to inform students the effects of radiation at the molecular, cellular and tissue level (morphological aspect) and the stochastic and deterministic (radiation dimension) results, directly related to Dose. Despite this, in Syllabus, there is no specific definition of what the Biological Effects are.

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[1] After the publication of ICRP 118 (2012), the term "deterministic" was changed to "acute". Despite this, as as this article is a bibliographic review, the term "deterministic" was kept when it was used by the author.

[2] After the publication of ICRP 118 (2012), the term " estochastic " was changed to "late". Despite this, as as this article is a bibliographic review, the term "estochastic" was kept when it was used by the author.

3.2. Dentistry

Regarding the publications in Brazil, in the area of radiological protection in dentistry, specifically about X-rays, it is said that their interaction with human tissue can generate biological effects that can be deterministic (high dose in a short time) and stochastic (small doses over a long period) and that these effects would be related to some factors, such as radiation dose, frequency, patient age, area size and type of irradiated cell [12].

3.3. Industrial

In the industrial area, in processes involving the sterilization of materials (using gamma radiation), an article found specific to the area, one does not even use the term Biological Effects. The concern of interaction with matter would be more concerned with sterilization *per se* than with the effects on Occupationally Exposed Individual organism. It is said that the ionization of matter by gamma radiation can alter its properties, favoring the cleavage (breaking) of the DNA chain of the microorganisms with the objective of eliminating them or rendering them incapable of reproducing, and the sterilization process depends on the total dose received by the objects to be sterilized [13].

3.4. Interventional medicine

For the area of Interventional Medicine, stochastic (probability of occurrence proportional to the dose of radiation received, without threshold) and deterministic effects (caused by total or localized irradiation of a tissue, leading to a degree of cell death not compensated for by replacement or repair, with detectable tissue or organ damage) are described.

It is also said that there is a dose threshold below which the loss of cells is insufficient to impair tissue or organ in a detectable manner.

There is also concern with the standards (citing in this case ICRP 10311, which warns of some radiation-associated effects, other than cancer) and the specificity of the lesions in Interventional Cardiology, such as tissue reactions (deterministic effect) and cataract formation, in physicians, and skin lesions in patients. It is also talked about units and doses [14].

3.5. Medical for emergency

It is worth mentioning a manual of medical actions for emergency, there is a prominence for the action of radiation in the cell's DNA molecule, whose injury can occur directly by the action of the radiation itself or by means of toxic radicals formed by hydrolysis (indirect). It also classifies the deterministic and stochastic effects, according to Table 1, in which it relates Effect, Existence of dose threshold, Severity of dose-dependent effect and Mediation [15].

Table 1: Deterministic and stochastic effects.

Effect	Dose Threshold Existence	Severity of dose-dependent effect Mediation	Example
Deterministic	yes yes	Cell death	SAR, SCR, effects in the embryo and fetus, hypothyroidism, cataract, infertility (sterility)
Stochastic	no no	Mutation	Cancer and congenital anomalies

Search: [15, p. 39].

3.6. Non-radiologist medical physicians

In the case of non-radiologist physicians, different types of ionizing radiation are said to promote different biological effects, the most appropriate concept being equivalent dose area (which takes into account the type of radiation involved in the exposure, by a factor of corrected for the value of the absorbed dose, whose magnitude is sievert – Sv) [16].

For X - rays, the correction factor is equal to 1 and therefore 1 gray – 1 Gy is numerically equal to 1 Sv - 3,12) [16]. The effects would then be:

> The biological effects caused by high energy ionizing radiation can be divided into deterministic or stochastic. The deterministic effects, or tissue reactions, are characteristic of high doses and depend directly on such exposure, such as cell death (for example, malignant cells undergoing radiotherapy), skin burns, sterility or the occurrence of cataracts (13, 14). At low doses, the risks are primarily of stochastic (or random) effects, which are those that are not apparent and that manifest themselves after months or years of exposure

> to radiation, not allowing a clear "cause and effect" relationship to be established, only a probability which is proportional to the dose. The most relevant stochastic effects are mutation and carcinogenesis (3,14,15). It is considered that, for stochastic effects, there is a linear dose-response component, without a threshold below which exposure is safe, ie any dose of radiation is likely to cause mutation or cancer (15) [16, p. 214].

There is still a concern with medical practice:

> In 2001, Brenner et al. (19) concluded that there may be up to 500 more cases of fatal cancer-related CT scans performed in the pediatric population annually in the United States, based on estimates of the number of exams performed and a protocol of Single abdominal CT, leading to virtually 1 case of fatal cancer for every 1,000 CT scans performed on children. Subsequently, in 2005, the Committee on the Biological Effects of Ionizing Radiation conducted an extensive review of the literature and developed risk projection models for the American population (15). The biological effects of ionizing radiation on the fetus in pregnant women exposed to ionizing radiation can be diverse, such as intrauterine death, malformations, growth and developmental disorders, and mutagenic and carcinogenic effects (27). The occurrence of these effects depends on the dose of radiation absorbed and gestational age (28). The American College of Obstetricians and Gynecologists (29) states that the risk to the fetus at exposures at doses less than 50 mGy is minimal. For a dose of 100 mGy, the increased risk of malformations or combined childhood cancer, above the population incidence, is around 1%. Radiographs (including mammography), fluoroscopy, and CT scans of areas other than the abdomen and pelvis expose the fetus to the lowest radiation dose. When they include the abdomino-pelvic region, these exams rarely exceed 25 mGy. The absolute risk of fetal effects is small for doses of up to 100 mGy and minimum for doses of less than 50 mGy. The most severe effects cited are more likely to occur at doses greater than 100 mGy (14). CT is not proscribed in pregnant women, especially in some clinical situations such as polytrauma or pulmonary thromboembolism. Whenever possible, priority should be given to methods known to be harmless to the fetus, such as US and RM (14) [16, pg. 215].

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3.7. Nursing

In the Nursing area, is said that if the patients were exposed to ionizing radiation for more than 20 minutes, this would be a worrying fact, since the biological effects of the radiation would depend on the absorbed dose, the exposure rate and the shape of the exposure, being directly proportional to the probability of damage, mutation, cell death, among other biological effects [17].

3.8. Radiation Physics

Finally, for the area of Radiation Physics, Biological Effects can be classified as to their mechanism, whether direct or indirect, and as to their nature, whether tissue reactions or stochastic effects. It also describes the stages of action, the mechanisms of action of radiation, the induction of other diseases to the hormesis [16-19].

When analyzing the radiological accident of Goiânia [18-20], the stages of radiation action in the body are presented:

1) Physical stage - where the ionization of an atom occurs in about 10-15 s.
2) Physical-chemical stage - when the chemical bond breaks occur of the molecules that underwent ionization, lasting about 6-10 s.
3) Chemical stage - when the fragments of the molecule bind to other molecules, lasting a few seconds.
4) Biological stage - that can last for days, weeks or even several decades when biochemical and physiological effects arise with morphological and functional alterations of the organs).

Besides that, are presented the mechanisms of action, that could be:

A. Direct - when the radiation interacts directly with the important molecules like those of DNA, being able to cause from genetic mutation to cellular; or
B. Indirect death - when the radiation breaks down the water molecule, thus forming free radicals that can attack other important molecules.

It is also said that because our body is composed of more than 70% water, the nature of the effects is different and can be Deterministic (high doses and only when arise above a certain dose, called threshold dose, whose value depends on the type of radiation and irradiated tissue; and Stochastic (changes that arise in normal cells, the main types are cancer and hereditary effect) [16-19].

After this review, was possible then prepare the Table 2, relating the area of knowledge found with the type of exposure (occupational or to the public).

Table 2: Definition of deterministic and stochastic effects by area of knowledge.

	EXPOSURE	
Area of Knowledge	**Public**	**Occupational**
PGEC Syllabus	X	X
Dentistry	X	X
Industrial		X
Interventional Medicine		X
Medical for Emergency	X	X
Non-Radiologist Medical Physicians	X	X
Nursing		X
Radiation Physics	X	X

Search: author.

4. CONCLUSION

As initially said, the idea of this paper was to make a bibliographical survey, mainly in Brazilian publications, of how different areas of knowledge understand and apply the question of Biological Effects.

In this way, it was possible to identify works in the areas of Radiological Protection and Safety of Radioactive Sources, Dentistry, Nursing, Non-Radiologist Medical Physicians, Medical Practice, Interventional Medicine, Radiation Physics, Industry and Emergency, all related to Radiological Protection and Biological Effects.

Thus, it can be verified that the classification and definition of Biological Effects will depend on the area of work or knowledge, where each one will focus on a certain aspect, such as Dose, the classification and nature of the effect, the time of action, characteristics the response of the organism, etc.

But in general it can be said that all areas classify the Effects in Deterministic or Stochastic. In the definition of deterministic effect was also found the expression Tissue Reaction.

In addition, it was verified whether the areas of knowledge analyzed the effects in a general or specific way (if occupational or for the public). It was observed that in all of them there is an occupational concern.

It is also worth noting that even doses as low 0.3-0.5Sv can induce acute effects, as those on skin. As stated on ICRP 118, a threshold dose of 0.5 Gy may be considered to a minimum limit to developing of acute effects. However, threshold setting for appearance of radiation effects is far from consensus, allowing researchers to argue according to their research.

Thus, this paper aimed to generate a debate on the various aspects that may be related to the subject, reaffirming the importance of the topic for the area of radiation protection. The final goal, upon completion of this review, is to prepare an Augmented Reality (AR) video in the future to assist in concept-setting and help students understand the definition of Biological Effects.

It is also understood that research on Biological Effects is of extreme importance for Radiological Protection, and that further studies on the topic are needed, since few studies have been found in Brazil.

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