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The impact of the Chernobyl nuclear power plant disaster on thyroid cancer – a review of recent reports

Wpływ katastrofy elektrowni atomowej w Czarnobylu na raka tarczycy – przegląd najnowszych doniesień

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Abstract

Introduction and Objective. The Chernobyl nuclear power plant disaster in 1986 is one of the most tragic in human history. In addition to the immediate effects as a result of the release of many radioactive isotopes, the distant health consequences play a huge role. Their scale is enormous and, at the same time, very difficult to determine precisely. One of the most significant aspects associated with a reactor accident, is the risk of cancer, even many years after the incident itself. The aim of the review is an attempt to provide an insight into the Chernobyl nuclear reactor accident as a factor affecting thyroid cancer.

Brief description of the state of knowledge. Most studies have consistently shown a significant effect of ionising radiation on the increased risk of thyroid cancer. Large amounts of radioisotopes released into the atmosphere have a well-documented effect on the occurrence of various thyroid gland cancers. In addition to methods of radiation absorption, such as inhalation of radionuclides, significant pathways of radiation exposure through the ingestion of contaminated milk or, for example, the effects of nitrates, have been described. The potential impact of radiation on thyroid tumours depends on the age group, gender and radiation dose received. Specific genetic mutations are also increasingly well studied and documented. Individual studies, however, cast doubt on the relevance of the correlation between the occurrence of thyroid cancer and the Chernobyl accident.

Summary. In view of the huge population effect of the Chernobyl disaster, it seems justified to carry out a thorough analysis of its aftermath – including long-term effects. This will not only allow us to improve our knowledge of the impact of radiation on cancer, but also, perhaps, enable more effective prevention in the event of similar incidents in the future.

Key words

cancer, thyroid cancer, Chernobyl, Chernobyl nuclear accident, radioactive fallout

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Streszczenie

Wprowadzenie i cel pracy. Katastrofa elektrowni atomowej w Czarnobylu, która nastąpiła w 1986 roku, jest jedną z najtragiczniejszych w historii ludzkości. Uwolnienie licznych izotopów radioaktywnych, do którego wówczas doszło, oprócz skutków natychmiastowych, niesie również odległe konsekwencje zdrowotne. Ich skala jest ogromna i jednocześnie bardzo trudna do precyzyjnego określenia. Jednym z najistotniejszych następstw awarii reaktora jest ryzyko wystąpienia chorób nowotworowych u osób narażonych na promieniowanie radioaktywne, nawet wiele lat po samym incydencie. W tym opracowaniu postaramy się przybliżyć zagadnienie awarii reaktora atomowego w Czarnobylu jako czynnika wpływającego na raka tarczycy.

Opis stanu wiedzy Większość badań konsekwentnie wykazuje istotny wpływ promieniowania jonizującego na zwiększone ryzyko wystąpienia raka tarczycy. Dobrze udokumentowano to, iż przedostanie się do atmosfery dużych ilości radioizotopów ma wpływ na wystąpienie różnych rodzajów nowotworów gruczołu tarczowego. Obok takich metod absorbowania promieniowania jak wdychanie radionuklidów, opisywane są istotne drogi napromieniowania za sprawą spożycia skażonego mleka czy chociażby narażenia na wpływ azotanów. Potencjalny wpływ promieniowania na nowotwory tarczycy zależny jest od grupy wiekowej, płci czy przyjętej dawki promieniowania. Coraz lepiej zbadane i udokumentowane są także konkretne mutacje genetyczne będące efektem napromieniowania. Istnieją również pojedyncze badania podające w wątpliwość korelację pomiędzy wystąpieniem chorób nowotworowych tarczycy a awarią w Czarnobylu.

Podsumowanie Ze względu na olbrzymi efekt populacyjny katastrofy w Czarnobylu zasadne wydaje się prowadzenie dokładnej analizy jej następstw – również tych długotrwałych. Nie tylko pozwoli to poszerzyć wiedzę na temat wpływu promieniowania na choroby nowotworowe, ale być może umożliwi także sprawniejszą profilaktykę w przypadku podobnych incydentów w przyszłości.

Słowa kluczowe

nowotwór, rak tarczycy, Czarnobyl, wypadek nuklearny w Czarnobylu, opad radioaktywny

INTRODUCTION

In 1986, there occurred one of the largest nuclear incidents in history, the disaster at the Chernobyl nuclear power plant in the area of today's Ukraine (then in the Union of Soviet Socialist Republics), resulting in a meltdown, explosion and fire in the nuclear reactor. The event had dramatic consequences. As a result of the fire which lasted for 10 days, huge amounts of radioactive substances – as much as 80 petabecquerels – were released into the atmosphere, contaminating a vast area. The highest levels of contamination and associated radioactivity were located primarily in the Chernobyl Exclusion Zone in Ukraine and Belarus. However, the effects of the tragedy were felt even in remote regions, such as Scandinavia, Austria and the UK. The area of contamination spread over more than 200,000 km2 of Europe and Eurasia [1] (Fig. 1).

After detonation of the atom bombs over Hiroshima and Nagasaki in 1945 and the Fukushima nuclear disaster in 2011, high doses of radiation also caused a significant increase in the incidence of thyroid cancer. Albi et al. note that the effect of radiation on the formation of thyroid tumours has been shown in atomic bomb survivors 62–66 years after childhood exposure. An analysis of the effects of the 2011 Fukushima nuclear reactor accident showed that 35% of the population developed thyroid nodules and/or cysts. A study of Hiroshima and Nagasaki survivors found that the risk of thyroid cancer was significantly higher if exposure to infrared occurred in childhood. Exposure to low to moderate doses of infrared seemed to particularly increase the risk of thyroid cancer, even if the exposure occurred in adulthood [2]. As a result of the disaster, in addition to the release of harmless radionuclides, such as xenon-133, other radionuclides such as iodine-131 and radioactive caesium-134, among others, were emitted [3].

Radionuclides released into the atmosphere as a result of the Chernobyl power plant disaster are shown in Table 1.

Table 1. Radionuclide emitted in the accident at the Chernobyl Nuclear Power Plant

Radionuclide	Half life	Radiation	Emission amount (PBq)*
Neptunium 239	58 hrs	β-rays, γ-rays	95
molybdenum 99	67 hrs	β-rays, γ-rays	>168
tellurium 132	78 hrs	β-rays, γ-rays	1,150
xenon 133	5 days	β-rays, γ-rays	6,500
iodine 131	8 days	β-rays, γ-rays	1,760
barium 140	13 days	β-rays, γ-rays	240
cerium 141	33 days	β-rays, γ-rays	196
ruthenium 103	40 days	β-rays, γ-rays	>168
strontium 89	52 days	β-rays	
zirconium 95	65 days	β-rays, γ-rays	196
curium 242	163 days	α-rays	
cerium 144	285 days	β-rays, γ-rays	116
ruthenium 106	1 year	β-rays, γ-rays	>73
cesium 134	2 years	β-rays	
plutonium 241	13 years	β-rays	
strontium 90	28 years	β-rays	
cesium 137	30 years	β-rays, γ-rays	85
plutonium 238	86 years	α-rays	
plutonium 240	6,850 years	α-rays, γ-rays	0.042
plutonium 239	24,400 years	α-rays, γ-rays	0.030

*PBq is equivalent to 10^{15} becquerel.

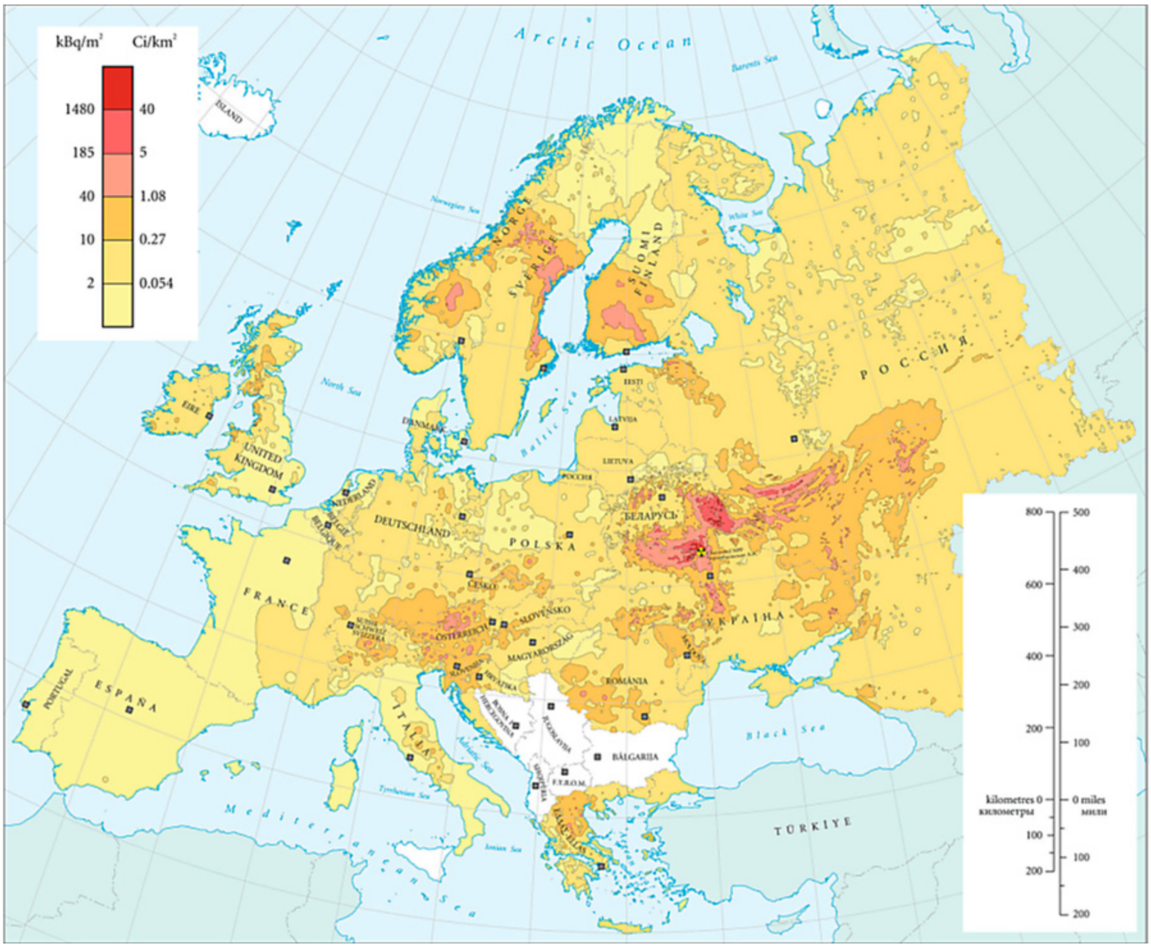

Figure 1. Chernobyl radioactive contamination map

Thyroid nodules are a common occurrence, are usually more common among women, and are especially common in iodine-deficient areas and those exposed to radiation. Depending on the examination technique, their incidence varies widely. On palpation, they are demonstrated in about 2–6%, on ultrasound 19–35% and on autopsy 8–65%. In developed countries, the higher incidence is associated with increasingly performed, precise imaging techniques, such as ultrasonography [4]. Tumours originating in the thyroid gland can be divided into those that originate in follicular cells and those that originate in neuroendocrine cells, which includes medullary thyroid carcinoma [5]. There are five main histological types of thyroid cancer (TC): papillary, follicular (also known as differentiated), poorly differentiated, anaplastic (the most aggressive form) and medullary. The heterogeneity of thyroid tumours is not only limited to histopathological diversity, but also manifests itself as variability expressed in genetic as well as epigenetic changes, and the number of interactions between the tumour and the surrounding microenvironment. These factors contribute to the complexity of tumour development from tumour cells [6].

Thyroid cancer is the most common endocrine neoplasm, accounting for 1% of all malignancies. Epidemiological data from the US National Cancer Institute Surveillance, Epidemiology and End Results (SEER) programme between 1975–2012 showed that 13.5 TC cases per 100,000 newly diagnosed cases were detected annually. According to 2015 data from the American Thyroid Association (ATA), the incidence rate of various types of TC almost tripled: from 4.9 per 100,000 in 1975 to 14.3 per 100,000 in 2009 [7]. During the first decade after the Chernobyl disaster, an approximately 100 times increase in thyroid cancer cases in children under 15 years of age was found in some areas of Belarus [8].

In addition to the afore-mentioned increased likelihood of cancers of the thyroid gland, among others, deterministic effects associated with ionizing radiation are also worth noting. Deterministic effects follow a clear cause-and-effect pattern. Below a specific threshold, no effect is observed; yet, once this threshold is surpassed, the effect grows consistently with each subsequent dose [9]. Deterministic effects are divided into fatal and non-fatal. Among fatal we include haematopoietic syndrome, gastrointestinal syndrome, pneumonitis, and embryonic or foetal death. Non-fatal includes moist desquamation, necrosis, acute radiation thyroiditis and hypothyroidism [10].

OBJECTIVE

The aim of the study was to conduct a comprehensive literature review focused on clarifying the link between the Chernobyl nuclear power plant disaster and the occurrence of thyroid cancer.

MATERIALS AND METHOD

A literature search was conducted using Google Scholar, PubMed, and Web of Science databases. Articles were searched by entering key words in the appropriate configuration: 'Chernobyl', 'thyroid cancer', 'cancer', 'Chernobyl nuclear accident', and 'radioactive fallout'. Scientific articles published between 2016–2024 were analysed.

DESCRIPTION OF THE STATE OF KNOWLEDGE

During the Chernobyl accident in 1986, a reactor type RBMK-1000, (Bolshoy Moshchnosty Channel Reactor, High-Power Channel Reactor) was damaged. It was developed by the former USSR, based on a reactor to produce plutonium for nuclear weapons, and was used exclusively on Soviet territory. At the time of the accident, 15 reactors based on this technology were in operation. Technically, the design of the RBMK reactor can be described as a graphite-moderator, boiling light-water cooling and channel-type reactor. It had quite a number of design flaws, such as: complexity of reactor control due to the large number of channels in the core, a positive void reactivity coefficient that appears when the steam fraction increases in the fuel channels, and also a 'positive scram' effect when all control rods are inserted into the core at the same time under certain extreme operating conditions [11].

Today's nuclear reactors are based on completely different, innovative technology, and the innovative boiling water reactor (BWR) – SWR-1000 (SiedeWasserReaktor" – the German word for BWR) – can be used as an example. The SWR-1000 meets the highest safety standards, including control of core meltdown accidents. Achievement of these goals is due to the use of passive safety systems with a variety of failure detection and control devices. The effectiveness of these systems has been confirmed by computer simulations of transients and LOCA (Loss Of Coolant Accident) failures and analysis of severe core melt accidents. In a core meltdown situation, numerical studies have shown that the melted materials would be retained inside the reactor vessel due to effective passive external water cooling. This protects the vessel from damage. It is also noteworthy that a power plant of this type is also protected from aircraft impact [12].

The first reported study by Francesco Marino and Luca Nunziata attempted to demonstrate a link between the radioactive Caesium-137 released during the Chernobyl disaster, which was dispersed over Europe, and the long-term health consequences with the cost of treatment. Due to Cesium-137's half-life of about 30 years, it is still detected in samples taken from radioactive fallout sites. The researchers made their assessment by comparing data on the incidence of malignant tumours (including thyroid tumours) between 2000–2013 in different, non-neighbouring areas of Europe directly adjacent to Chernobyl. By dividing the concentrations of caesium in the samples and assessing them as low, medium and high, they found an increase in incidence of 0.36, 0.44 and 0.98, respectively, after hospitalisation for cancer (population average, approximately 1.7 per 100 inhabitants).

The results of their observations showed a positive correlation of the effect of radioactive fallout on the higher incidence of cancer in the study region, almost 30 years after the Chernobyl disaster. The incidence of cancer was related to the amount of radioactive substance released – in areas of higher radioactivity, the incidence was significantly higher. Scientists taking these facts into account, and the scale of the disaster, emphasise the important role in view of the enormous significance for safety and public health [13].

In another study, Giedre Smailyte ret al. assessed the risk of cancer in adults exposed to radiation as a result of the Chernobyl disaster. The study examined a well-defined group of people – a Lithuanian cohort of workers involved in the clean-up of waste after the nuclear power plant explosion. An assessment was made of 6,707 men and their risk of cancer 26 years after the disaster. A higher incidence of cancers of the mouth and throat was found. In addition, clean-up workers under the age of 30 at the time of the disaster were shown to have a higher risk of thyroid cancer [14].

An assessment of the impact of iodine-131 (I-131) as a major potential carcinogen released as a result of the Chernobyl disaster, was undertaken by […]. Focusing on the evaluation of this radionuclide on thyroid tumours, much of the study's attention was on radiation doses. They showed that ingestion of large amounts of the radioactive isotope was most significant in the intake of contaminated cow's milk and was significantly higher than inhalation of it in the air. In the most exposed are, the Gomel region of Belarus, the population average dose of I-131 ingested with cow's milk was determined to be 0.75 Gy. This result depended on age, geographical region and amount of milk consumed, but reached up to 42 Gy. Among the decommissioners, the workers cleaning-up Chernobyl after the disaster who also had the highest risk of exposure to the highly concentrated I-131 in the air, this result was estimated at 0.18 Gy, with the highest value reaching up to 9 Gy. The results of this study demonstrate the role of I-131 as the most important radionuclide to increase the incidence of thyroid cancer and other thyroid diseases in exposed individuals [15].

Another study by Wolfgang Weiss examined the role of cow's milk and its consumption as the predominant I-131-containing factor influencing the incidence of thyroid cancer. Among a research group whose participants were 10-years-old at the time of the Chernobyl disaster, thyroid cancer cases were found to increase over time (data recorded between 1991–2015). These cancers were more than four times more common among women. The author stresses the important role of developing guidelines called 'good practice' for dealing with analogous disasters. In the author's opinion, these should include but not be limited to such aspects as: measuring doses of I-131 that may affect the thyroid gland, analysing the incidence and risk assessment of thyroid cancer, or even psychological support for sufferers and their families [16].

Alexey A. Efanov et al. found that the impact of ionising radiation occurring during adolescence is a well-documented risk factor for thyroid cancer, and explore its genetic mechanisms. In individuals exposed to I-131 as a result of the Chernobyl disaster, they investigated the genetic basis of papillary thyroid cancer using next-generation sequencing and RNA-Seq technologies. The data obtained from the analyses suggest a clear association between the dose of I-131 in the thyroid and the occurrence of carcinogenic gene fusions, which appeared to be the predominant mechanism of papillary thyroid cancer among the subjects [17].

In another article, the authors assessed the occurrence of somatic health effects 30 years after the Chernobyl disaster. According to them, in the areas most exposed to radiation, almost 11,000 cases of thyroid cancer were reported among people who were children at the time of the nuclear power plant explosion. Taking into account factors other than radiation, it was concluded that one of the most significant carcinogens was exposure to I-131. The role was emphasised of histopathological examination of the materials contained in the 'Chernobyl Tissue Bank' and their molecular analysis, with particular emphasis on gene fusions and chromosomal aberrations. Also addressed was the issues of radiation-increased risk of malignant diseases, such as leukaemia and lens opacity. In the context of diseases in general, the article drew attention to the possibility of genetic effects in the offspring of radiation-exposed individuals [18].

Noboru Takamura described the probability of thyroid cancer in a population of children exposed to radiation released as a result of the Chernobyl disaster, while also comparing it with the risk in the Japanese population exposed to radiation associated with the explosion at the Fukushima nuclear power plant in Japan in 2011. Among paediatric patients, as a result of the 1986 Chernobyl explosion, the average radiation doses to the thyroid gland in children were about 560 mSv in Belarus and 770 mSv in Ukraine. In Belarus, according to a register set up before the disaster, there were 25 cases of operable thyroid cancer in patients aged 0–15 years during the first four years after the accident (1986–1989). This number increased to 431 in 1990–1994, 766 in 1995–1999, and 808 in 2000–2003 (Fig. 2) [19].

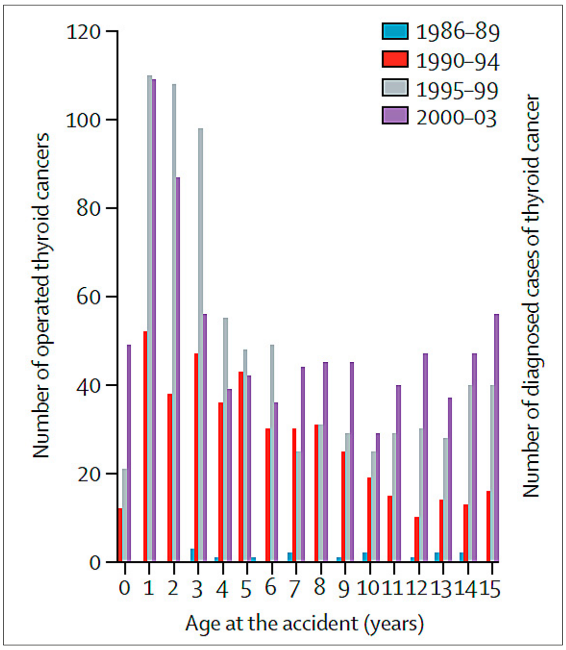

Figure 2. Numbers of operated thyroid cancers in patients aged 0–15 years at the accident in Belarus

Sarah B. Fisher et al. performed a characterisation of the genetic features of medullary thyroid cancer in children who survived the Chernobyl disaster. In available tissue samples from 49 individuals, both somatic and germline genetic alterations, including RET fusions, were assessed. These were analysed in pooled samples of medullary thyroid cancer tumours and normal tissues from the Chernobyl Tissue Bank. The mean age at diagnosis was 26 years. Of the subjects, 16 had been exposed to radiation for an average of six years (range two days to 17 years). Twenty-one patients showed germline RET mutations; of these, four also had a family history of cancer. Of the 27 patients, cases of sporadic medullary thyroid cancer were identified, in whom no association was found between radiation and age of surgery, tumour size or tumour progression. In the study cohort, genetic analysis revealed germline RET mutations in previously undiagnosed individuals, and a significant number of sporadic medullary thyroid cancer cases that occurred at a young age [20].

Fridman et al. conducted a large study on the complications of thyroid surgery for papillary thyroid cancer in children. Among other things, they divided patients into three. groups in the study. In the group of patients with papillary thyroid cancer attributed to external irradiation (following radiation treatment for childhood malignancies), a total of 25 cases treated surgically between 1995–2010 were identified. This category was defined as 'associated with external irradiation'. The second group, known as the 'post-Chernobyl' group, included 936 patients affected by internal radiation in different situations and with different doses of I-131 (with an area-specific radioactivity level of I-131 exceeding 185 kBq/m2). These patients underwent surgery between 1990–2005, i.e. after the Chernobyl event. The third, 'sporadic' group included 208 patients who underwent surgery for papillary thyroid cancer between 1991–2010, who were born between 1987–1992.

Although no difference was shown in the overall complications in these groups, it appeared that the 'post-Chernobyl' group (Group 2) had a greater extent of thyroid cancer with a high incidence of lymph node metastasis, frequent recurrence and a higher incidence of distant metastasis [21].

Valentina M. Drozd et al. describe the role of nitrates as modulators of risk after radiation exposure, with particular reference to the Chernobyl disaster. The role of radiation is a well-documented factor involved in thyroid cancer. However, the influence of other factors, as well as interfering elements, and their synergistic effects are less well understood. Research on thyroid cancer following the Chernobyl disaster has shown that children living in areas with high nitrate concentrations in drinking water had a significantly increased risk of thyroid cancer. A possible explanation for this phenomenon is that the effect of radiation may be modified by the presence of nitrates in the body [22].

In the following study […], the authors attempt to comprehensively summarise the issue of the incidence of thyroid cancer in the paediatric population, in relation to exposure to radiation released as a result of the Chernobyl disaster. The authors indicate the over-arching role of radiation in the pathogenesis of these cancers and present the incidence first increased after a 4-year latency period in the youngest age group (0–9 years old at the time of the accident). The high radiation doses to the thyroid (up to 750 mGy) were mainly due to the consumption of food and contaminated milk. In clinical manifestation, radiation-associated childhood cancers differed from sporadic ones mainly in their higher incidence in boys and children of the youngest age, and also in distant metastases. On the other hand, lymph node metastases were very common in both irradiated and sporadic cases. Despite signs of aggressive tumour behaviour, more than 95% of cases had a 15-year overall survival rate. However, it should be borne in mind that in about 30% of patients, patients' quality of life can be significantly reduced by tumour recurrence. Approximately 50% of patients suffered from treatment-related side-effects, which are more or less unavoidable if the goal of treatment is high long-term survival, especially in patients with advanced-stage tumours [23].

Another study, conducted by Oleksandr Oliynyk et al., aimed to investigate the effects of increased radiation exposure and iodine deficiency on the incidence of thyroid cancer among Ukrainian residents. The Ternopil area was divided into three zones according to dietary iodine content and radiation levels, and patients were then grouped by age and gender.In 2016, thyroid cancer incidence and prevalence rates in males were 4–6 times lower than in females in all areas studied. In the female population in areas of increased radiation, an average increase in incidence rate of 1.25–3.2, depending on age, was observed compared to areas with normal radiation. The incidence rate in women in areas of increased radiation and iodine deficiency was 1.54–5.4 times higher than in uncontaminated areas. The highest incidence rates of thyroid cancer in the Ukrainian region were observed in women over 51 years of age. The incidence of cancer in areas with iodine deficiency and increased radiation was twice as high and the number of cases was three times higher than in women from areas with normal iodine and radiation levels [24].

The studies by Sergei V. Jargi, however, are in opposition to previous results. He indicates doubts about the causal relationship between radiation exposure after the Chernobyl disaster and the increase in the recorded incidence of cancer. The author does not deny the link with cancer incidence *per se,* but questions whether the correlation was correctly estimated [25]. The researcher argues that emphasising the effects of the Chernobyl disaster may be misleading, especially regarding the carcinogenicity of low doses of radiation, especially radioiodine. He argues for the need to re-evaluate the results of some of the molecular-genetic studies related to the Chernobyl disaster, taking into account that many of the tumours detected by screening in the first decade after the disaster, or transferred from uncontaminated areas and classified as exposed to fallout, were in fact advanced cancers. Consequently, some potential radiation-related cancer markers may be more related to disease duration and tumour progression. Accordingly, although monitoring populations exposed to low doses of radiation is important, it does not yield much reliable information on health risks. Animal experiments should be used as an alternative for future work, given that life expectancy is a sensitive indicator related to radiation exposure. Experiments with different animal species could allow a more accurate quantification of their radiation sensitivity, which would allow more precise extrapolations to humans [26].

The Chernobyl nuclear power plant disaster resulted in a number of important medical consequences. Despite individual dissenting voices, one of the best documented and confirmed effects is the impact of the accident on the risk of thyroid cancer. Despite the fact that almost 40 years have passed since the explosion, until now the health aspect of this phenomenon remains of interest to scientists worldwide. Thanks to modern technology, the mechanisms of carcinogenesis and the impact of radionuclides released into the atmosphere on the occurrence of thyroid cancer are increasingly being understand. The scale of the phenomenon, although difficult to define precisely, is also being increasingly studied. It is noteworthy that not only inhalation exposure is a significant factor in the development of thyroid cancer, but the consumption of contaminated food, e.g. cow's milk, is also mentioned in many studies. In view of the long-lasting effects of radioisotopes, it seems reasonable to continue to monitor the health of the population and to conduct research into the impact of the Chernobyl nuclear power plant accident on thyroid cancer.

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