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Original Research

Assessment of Work Environmental Hazard and Exposure of a Worker Utilizing ^{226}Ra in an Oncological Center

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Abstract

Our study presents dosimetric evaluation of activities associated with sealing in glass 72 sources of ^{226}Ra prepared for utilization, and of the effect of an absorbed dose on a worker's select laboratory parameters. During 3 h exposure to ^{226}Ra of activity 31 GBq, it was demonstrated that taking the sources from a bunker in portions only for the time of sealing them in glass, decreases the worker's exposure to the obtained dose from 91.5 mSv to 6 mSv, and additionally used 5 cm shield to 2 mSv. Nine days after the worker's absorption of the radiation dose, we observed in laboratory tests disorders expressed by decreased numbers of white blood cells and neutrophils, decreased activity of antioxidative enzymes in erythrocytes, concentrations of protein thiol groups, vascular endothelial growth factors in serum, and an increase of plasma total antioxidant status level, of insulin-like growth factor I level, and urokinase-type plasminogen activator receptor level in blood serum.

Keywords: ^{226}Ra, free radicals, radiation exposure, biochemical parameters

Introduction

The name radium was given to this element by its discoverers Marie and Pierre Curie in 1898, and it is derived from a Latin word radius, or ray.

Radium is a silverish, luminescent, and soft metal. It is a divalent element demonstrating characteristic properties of alkaline earth metals. Its melting point is about 700ºC and boiling point 1,400ºC. Its chemical properties are similar to those of magnesium. It reacts relatively slowly with atmospheric oxygen, forming an oxide RaO and quite rapidly with water-forming hydroxide $Ra(OH)_2$. At present, 30 radium isotopes are known but only 4 of them are found in nature, and ^{226}Ra is one of them [1]. The half-life for ^{226}Ra is the longest of all its isotopes at 1,620 years. It is an emitter of alpha radiation (E_α=4.6 and 4.78 MeV) and gamma radiation (E_0=1.7 MeV).

Radium was applied in industry, medicine, and scientific research. Its wide use in radiography, as a component of luminescent paints and in the treatment of cancer, are only a few examples of the application of this element in the past [2]. Due to marked radiotoxicity with which the increase in the prevalence of bone and blood neoplasms was associated, ^{226}Ra was replaced with short-lived radioactive isotopes

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of other elements. ^{226}Ra gets into a human organism through the digestive system or skin, or it can be inhaled. In normal conditions the main route for radium to enter the human organism from natural environment is digestive system [3, 4]. Radium is absorbed in intestines only in 20% and it competes with calcium [5]. When absorbed, it is deposited mainly in bones, although in the initial period after exposure, 1/3 of total activity is deposited in soft tissues [6]. As bones are a critical tissue for radium, marrow cells, osteoblasts, and epithelial cells on the bone surface become the most exposed and the most sensitive to radiation [7, 8]. In extreme conditions at continuous inhalation of ^{226}Ra, the amount of this element deposited in the respiratory system can be significant, while in other organs its content will be low [9]. The aim of our study was dosimetric evaluation of activities associated with sealing in glass 72 sources of ^{226}Ra of total activity 31 GBq prepared for utilization, and investigation of the effect of the absorbed dose on selected laboratory parameters of a worker.

Material and Methods

The investigations were carried out at the Copernicus Provincial Hospital in Łódź, where there were 72 sources of ^{226}Ra of total activity 31 GBq. Radium had been used in this Hospital for several dozen years for brachytherapy. In June 2006 radium sources were utilized. While sealing the sources in glass the mean distance of a worker from the sources was 0.5 m, and the time of exposure was 3 hours.

Estimation of the radiation risk prognosticating the worker's emergency was performed based on:

1. Mathematical calculation of:

a) the absorbed dose rate [10]

$$\dot{D} = \frac{\Gamma r \times A}{l^2}$$

b) the absorbed dose for unshielded source [10]

$$D = \frac{\Gamma r \times A \times t}{l^2}$$

c) the absorbed dose for a source behind a 5 cm lead shield [10]

$$D = \frac{\Gamma r \times A}{K \times l^2}$$

d) the equivalent dose [10]

$$H = \frac{D}{0.087} mSv$$

2. Dosimetric measurements performed with film dosimeters placed on a lead wall (environmental photometer) and on the worker's chest (personal photometer).

To assess the danger of the damage to work environment and of the exposure of a worker utilizing ^{226}Ra, the following were performed:

1. Dosimetric measurements of surfaces that radium sources were in contact with. Measurements were performed with a contamination meter EKO-C/S with a scintillation probe SSA-1P.
2. Measurements of the dose rate distribution on the surface of shipping containers after placing the sources in them. The measurements were performed using a DP-75 X-ray radiometer.
3. Measurements of the dose rate on the outside surface of a car after loading the containers with the sources. The measurements were performed with a DP-75 X-ray radiometer.

The effect of the absorbed radiation dose on the organism was estimated on the basis of laboratory tests performed 24 h before the worker's contact with radium sources and on the 9th day after sealing the sources. The test included:

1. White blood cells volume distribution with Beckman Coulter LH 750.
2. Plasma concentration of vascular endothelial growth factor (VEGF) [11], insulin-like growth factor I (IGF-1) [12] and urokinase-type plasminogen activator receptor (uPAR) [13]. The tests were performed with ELISA immunoenzimatic method using R&D Systems reagents.
3. Superoxide dismutase activity in erythrocytes (SOD) (EC 1.15.1.1) with Misra and Fridovich method [14], catalase activity (CAT) (EC 1.11.1.6) with Beers and Sizer method, and glutathione peroxidase activity (GPx) (EC 1.11.1.9) [15] with Little and O'Brien method [16].

Moreover, total plasma antioxidant activity (TAS) was determined according to Benzie and Strain [17], the presence of protein thiol groups (SH) with Ellman reagent according to Rice-Evans et al. [18], and malondialdehyde (MDA) concentration in erythrocytes with Placer et al. method [19].

Results and Discussion

I. The results of dosimetric measurements:
- The dose rate on the surface of shipment containers did not exceed 2 mSv/h
- The dose rate on the outside surface of the car did not exceed 0.5 mSv/h
- The dose on the environmental photometer was 6 mSv and on personal photometer 2 mSv.

II. The results of mathematical calculations:
- The rate of the dose absorbed by a worker was 2.7 $cGyh^{-1}$ (activity of the sources (A) was 31 GBq, the distance (1) of a worker from the sources was 0.5 m, equivalent value of the exposure constant (Γ_Γ) for ^{226}Ra had a value of 21.4×10^{-3} $cGyh^{-1}$ $CBq^{-1}m^2$.
- The dose absorbed in the air (D) in 3 hours was 8.0 cGy.
- A person working for 3 hours 0.5 m from the unshielded 72 sources of ^{226}Ra of total activity 31 GBq would be exposed to a dose (H) of 91.5 mSv.

In Poland the maximum dose of annual exposure for a worker is 20 mSv. A dose of 91.5 mSv approximately corresponds with a maximum 5-year dose to which a person working professionally with the sources of ionizing radiation can be exposed. Work in such conditions is strictly forbidden. Regulations concerning the radiological protection order apply the rule As Law Reasonably Achievable (ALARA). According to this principle, evaluation of factors enabling reduction of such high doses should be performed.

To decrease the exposure and to limit the absorbed dose, a 5 cm lead shield was placed between the sources and the worker. In the case of ^{226}Ra a lead shield weakens 10-fold the absorbed dose. A person working in such conditions would be exposed to a dose of 9.2 mSV. It is a dose permitted for part of workers in Poland on condition that within a year they would not be exposed in total to a dose higher than 20 mSv. Further analyses revealed that an additional shield would make access to the sources more difficult and the distance of 0.5 m was optimal for performing manual activities. The limitation of the dose could be achieved only by shortening the exposure time. Appropriate preparation of ampoules for sealing and the use of a hand gas burner enabled efficient optimal activity as regards radiological protection. The most important elements decreasing the exposure dose were:

1- Single partial pulling out a slide of the drawer with the sources
2- Placing 5 radium sources of mean activity of about 2 GBq in an ampoule while the other sources are locked in a bunker for the time of the ampoule sealing.
3- Immediate placing the sealed ampoules in the bunker lead shield.

Ionizing radiation affects the organism directly and indirectly through water radiolysis. Electron (e-aq) and water radical cation $H_2O^{\cdot+}$ which, when disintegrating, form hydroxyl radical, are products of radiolysis. Hydroxyl radical together with $H^{\cdot}$ may also be a direct product of water molecule degradation, and they also can form hydrogen peroxide molecule [20]. DNA damage comes as a result of its interaction with reactive oxygen species [21, 22]. Cell death [23, 24] or its mutation [25] may be a consequence of DNA damage. Cell damage depends, among other things, on the type of radiation, the rate of fractional dose, integral dose, and dose rate [26, 27]. In this study, total white cell count was performed to detect the effect of the absorbed radiation dose on blood cells. Comparing the test performed before and after the worker's exposure to radium sources, a decrease in WBC by 4.5% and in NE by as much as 12% was observed. The test was repeated on the 9th day after radiation due to earlier observations of maximal decrease in the number of neutrophils from the 7th to 20th days of exposure. The effect of the absorbed radiation dose on angiogenesis, apoptosis, and carcinogenesis was assessed by the determination of the worker's plasma VEFF and IGF-I concentrations. VEGF (vascular endothelial growth factor) is a key factor regulating physiological and pathological angiogenesis. VEGF is a mitogenic factor for epithelial cells of vessels originating from arteries, veins, and lymphatic vessels, and it promotes their proliferation [28]. In neoplastic disease it comes to pathological angiogenesis. Increased VEGF expression was found in colon cancer [29], breast cancer [30], non-small cell lung cancer [31], ovarian cancer [32], kidney and pancreatic cancer, and in acute myeloid leukemia [33].

IGF-1 (insulin-like growth factor 1) is a single-chain polypeptide of 70 amino acids of mitogenic activity. It takes part in processes of growth, carcinogenesis, apoptosis, wound healing, and other ativities. It is responsible for the regulation of metabolic processes, and its proper function-

Table 1. The results of laboratory tests.

	Tested parameter	T0 – numerical values before a worker's exposure to radium T9 – numerical values on the 9th day after exposure to radium
1.	White blood cells (WBC)	T0 – 7.0×10^3
		T9 - 6.7×10^3
2.	Neutrophils (NE) [µl]	T0 – 4.2×10^3
		T9 – 3.7×10^3
3.	Lymphocytes LY [µl]	T0 – 1.9×10^3
		T9 – 2.1×10^3
4.	Monocytes (MO) [µl]	T0 – 0.7×10^3
		T9 – 0.7×10^3
5.	Eosinophils EO [µl]	T0 – 0.1×10^3
		T9 – 0.2×10^3
6.	Basophils BA [µl]	T0 – 0.0×10^3
		T9 – 0.0×10^3
7.	Human VEGF [pg/ml]	T0 – 63.4
		T9 – 37.4
8.	Human IGF-1 [ng/ml]	T0 – 100.4
		T9 – 155.8
9.	Human uPAR [pg/ml]	T0 – 295
		T9 – 576
10.	SOD [U/gHb]	T0 – 2,708.6
		T9 – 2,395.6
11.	CAT [U/gHb]	T0 – 20.5
		T9 – 18.5
12.	Gpx [U/gHb]	T0 – 9.5
		T9 – 6.24
13.	TAS [µmol]	T0 – 141
		T9 – 389
14.	MDA [nM/gHb]	T0 – 0.2
		T9 – 0.2
15.	SH [mM/L]	T0 – 1.0
		T9 – 0.9

ing conditions organism homeostasis [12, 34]. In a worker exposed to a dose of radiation, VEGF level decreased by 41% and IGF-1 level increased by 52%.

uPAR (urokinase-type plasminogen activator receptor) are receptors found on the surface of monocytes, neutrophils, or neoplastic cells [35]. They illustrate the process of fibrinolysis on the cell surface. Disturbances in coagulation and fibrinolysis may signal clinical symptoms of neoplasia. In a worker exposed to a dose of radiation, uPAR increased by as much as 95%.

Radioactive compounds generate free radicals in living organisms which in turn disturb the organism oxidation-reduction balance, moving it toward an increase in oxidations. Thus, in erythrocytes of a worker exposed to radium the activity of basic enzymes neutralizing free radicals, including superoxide dismutase (SOD) (EC 1.15.1.1), catalase (CAT) (EC 1.11.1.6), and glutathione peroxidase (Gpx) (EC 1.11.1.9), was determined. The activity of the investigated enzymes decreased after exposure to radium for SOD by 11.6%, whereas for CAT and Gpx by over 34%. The worker was compensated for the impoverishment of antioxidative enzyme activity by an increase in the level of a series of low-molecular antioxidants, the measure of which is total antioxidant status (TAS) in plasma.

On the 9th day after exposure to ^{226}Ra, the value of TAS increased by 176%. Perhaps the increase of TAS value was the cause of the lack of changes in the level of MDA lipid peroxidation products, the increase of which was expected after exposure to radiation.

Moreover, in our own studies the changes were detected in the concentration of protein sulfhydryl (SH) groups, owing to sulfhydryl group proteins playing the role of redox buffer. They are an element of TAS. Increased exposure to reactive oxygen species leads to a decrease in the content of SH groups in proteins. In one worker, SH levels decreased after exposure to ^{226}Ra by 11.7%, which may prove earlier oxidative damage of proteins than of lipids. Total serum antioxidant levels in permanently exposed people was significantly lower than the individuals not exposed to a high dose natural ionizing radiation [36].

Changes in laboratory parameters of a worker taking part in radium utilization may be of importance when the fact is taken into account that in some oncological centers in Poland, and perhaps also in the world, there are unused sources of radium-226 in the amount of a few hundred milligrams in each center [37]. The poisoning of KGB defector Alexander Litwinienko with 1 μg of radioactive polonium (^{210}Po) stimulates the imagination and calls for precautions. Both ^{210}Po and ^{226}Ra are emitters of α-radiation.

Conclusions

It was demonstrated that during 3 h utilization of ^{226}Ra of 31 GBq activity, taking out the sources from a bunker in portions only for the time of sealing them in glass decreases a worker's exposure to the obtained dose from 91.5 mSv to 6 mSv, with the additional application of a 5 cm shield to 2 mSv.

On the 9th day after absorption of the radiation dose, the following disorders were observed in laboratory tests.

1. Decreased number of WBC and NE, decrease of antioxidative enzyme activity in erythrocytes, decrease of serum protein SH groups and VEGF levels.
2. Increase of total plasma antioxidant status level, IGF-1 and uPAR level in blood serum.

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