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Preliminary assessment of dose distribution on the spatial micro level for internal exposure of alveolar epithelium of rats by ^{56}Mn

Special dosimetry study of experimental rats exposure by sprayed ^{56}Mn powder was conducted during experiments in order to study internal irradiation effects. All experiments were performed in Kurchatov's reactor complex «Baikal-1» (Kurchatov city, East-Kazakhstan region) after neutron activation of stable Mn powder. This study was performed by group of scientists from Japan, Kazakhstan, and Russian Federation. The results of estimated doses in lungs alveolar epithelium of rats are shown in this paper. Absorbed dose on the «surface» of epitelium is equal to 160 Gy and absorbed dose in the «bottom» of epithelium for minimal thickness of epithelium cells is 8.9 Gy and for maximal thickness of epithelium cells equal to 0.4 Gy.

Keywords: internal exposure, Kurchatov, MCNP, rats, organs, powder of ^{56}Mn, epithelium layer.

Introduction

It was important to study effect of radiation, due to effect of possible influence to human, and effect of possible internal exposure because of close location to Semipalatinsk Nuclear Test Site and post effect of irradiation due to Hiroshima and Nagasaki atomic bombing, Chernobyl, and Fukushima-1 accidents [1–4].

At neutron irradiation, including such kind of extraordinary tragedy as A-bombing of Hiroshima and Nagasaki, the ^{56}Mn ($T_{1/2}$=2.58 hour) was one of the dominant neutron activated irradiators during the first hours following the neutron irradiation. Modeling of irradiation by residual radioactivity from activated dust using neutron-activated ^{56}Mn in a form of powder sprayed over experimental rats was conducted recently [5]. Activation of MnO_2 (manganese dioxide) powder was performed using the IVG.1M nuclear reactor («Baikal-1» experimental facility, Kurchatov city, Kazakhstan).

According to V. Stepanenko, et al. [6, 7], mean organ doses of internal irradiation of rats by ^{56}Mn powder are the following: 1.65, 1.33, 0.24, 0.1, 0.076 Gy, in large intestine, small intestines, stomach, lungs, and skin respectively.

The essential pathological effects were found in gastrointestinal tract [8, 9]. On the other hand, despite relatively low dose in the lungs (0.1 Gy), the hemorrhage and emphysema were found in this organ as well [8]. It is very difficult to interpret this fact, as far as these effects are observed at much larger doses of external irradiation.

As a result, due to ideas of Prof. M. Hoshi [5] and Prof. M. Ohtaki [10, 11], it was decided to estimate not only mean organ doses of internal irradiation, but distribution of dose on microlevel of biological tissue, particularly on the level of alveolus of lungs. Short range irradiation from ^{56}Mn (Auger electrons, low energy X-rays) can be a reason of much larger doses in microstructures of lungs.

Material and Methods

Monte Carlo code (MCNP-4C) with corresponding Library of cross sections for electrons and quanta was used for calculation of absorbed doses in biological tissue around $^{56}Mn0_2$ microparticles (density of manganese dioxide is 5.03 g/cm^3). Mean diameter of $^{56}Mn0_2$ microparticles is equal to 4 μm. The corresponding data of ^{56}Mn's Auger electrons, X-rays, beta particles < and gamma-rays are resented in Tables 1–3 and in Figure 1.

Irradiation of ^{56}Mn

Table 1

^{56}Mn: AUGER ELECTRONS

Type	Energy keV	Electrons/decay	R99, (loss of 99 % of initial energy at R99 – radius of tissue sphere around isotropic microsource), cm
KLL	5.51	1	8.8 E-6
KLX	6.28	0.274	1.1 E-4
KXY	7.01	0.0187	1.3 E-4
L	0.57	3.07	2.1 E-6

Table 2

^{56}Mn: X-RAYS

Type	Energy keV	Photons/decay	R99, (loss of 99 % of initial energy at R99 – radius of tissue sphere around isotropic microsource), cm
Kα2	6.39	0.51	
Kα1	6.40	1	about 1 E-2 cm
Kβ1	7.06		
Kβ5	7.10	0.21(total for all Kβ)	

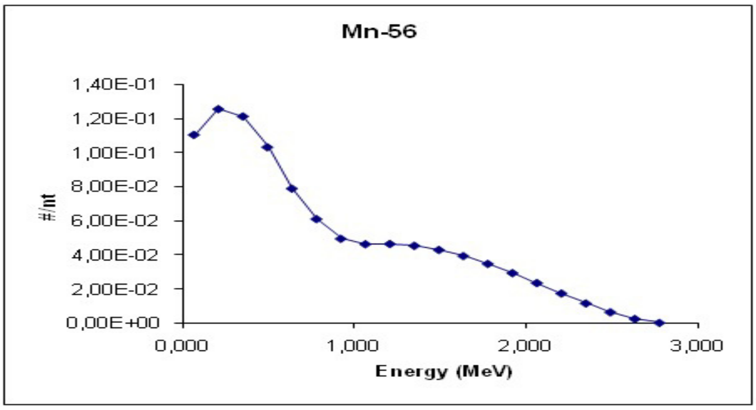

Figure 1. Beta particles of ^{56}Mn: intensity is 100 %, average energy is 829.21 keV (mean R99 is about 1.8 cm), and maximal energy is 2848.00 keV (maximal R99 is about 6 cm)

Table 3

^{56}Mn: MAIN GAMMA-RAYS

Type	Energy keV	Photons/decay	R99, (loss of 99 % of initial energy at R99 – radius of tissue sphere around isotropic microsource), cm
Gamma-1	846.8	0.989	about 80 cm
Gamma-2	1811	0.272	> 100 cm
Gamma-3	2113	0.143	> 100 cm
Gamma-4	7.10	0.173	> 100 cm

Geometry of calculation

Alveoli of lungs are the final destination for inhaled air and for microparticles entering into the lungs with air. Each alveolus is lined with squamous epithelial cells (from 0.05 mkm to 0.3 μm thick). Surfactant (which is over epithelial cells) is about 0.01 μm thickness. So, if 56Mn microparticle is attached to epithelium, the minimal distance to the «surface» of epithelium layer will be 1×10-6 cm and maximal distance to the «bottom» of epithelium layer will be 6×10-6 (in a case minimal thickness of epithelium cell) or 5×10-5 cm (in a case maximal thickness of epithelium cells) (Fig. 2). Absorbed doses were calculated in spherical layers of biological tissue around ^{56}Mn microparticle.

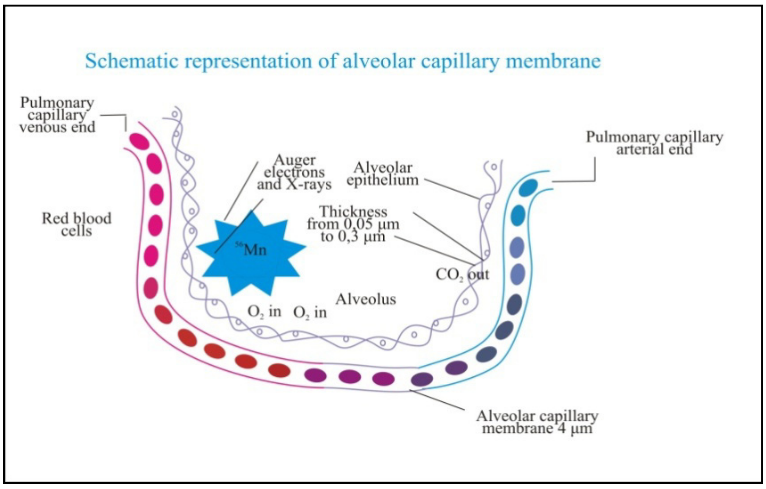

Figure 2. Schematic representation of lung's alveoli with $^{56}MnO_2$ microparticle.

Results and Discussion

It was estimated, that mean initial activity of one $^{56}MnO_2$ microparticle is equal to 0.196 Bq (with total activity of 0.1 g, MnO_2 equal to 2.74×10^8 Bq, according to Hoshi, et al. [5]. Period of ^{56}Mn physical half decay is equal to $T_{1/2}$ = 2.58 hours = 9.288x10^3 seconds. Total number of ^{56}Mn decays up to whole decay in one ^{56}Mn microparticle with estimated activity 0.196 Bq is equal to: N=0.196 Bq×9.288x10^3 seconds/0,693 = 2.627×10^3 decays. Dose per one decay from Auger electrons, low energy X-rays, and beta particles of ^{56}Mn is presented in Figure 3. This figure shows results of calculations of spatial dose distribution around ^{56}Mn placed into biological tissue.

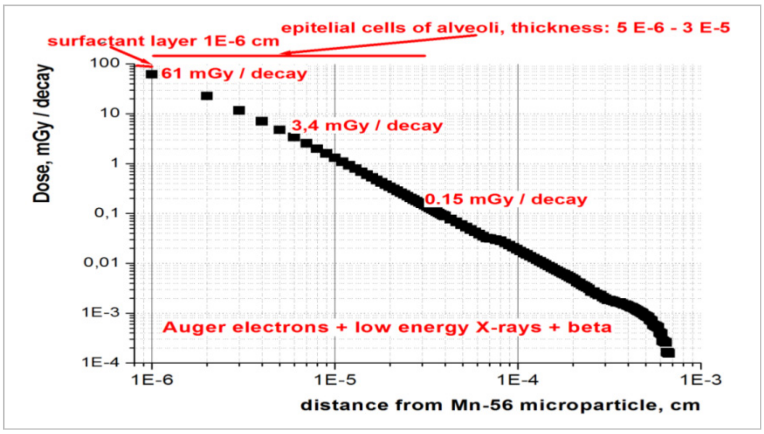

Figure 3. Results of calculations of spatial dose distribution around ^{56}Mn microparticle placed into biological tissue.

So, as result, these estimations shows the following doses per decay: 61 mGy/decay at distance 1×10^{-6} cm from microparticle («surface» of alveolar epithelium layer); 3.4 mGy/decay at distance 6×10^{-6} from microparticle («bottom» of alveolar epithelium layer, in a case of minimal thickness of epithelium cell); 0.15 mGy/decay at distance 3×10^{-5} cm from microparticle («bottom» of alveolar epithelium layer, in a case of maximal thickness of epithelium cell). Highest dose is due to short distance to radioactive source.

Total absorbed dose (up to whole decay of ^{56}Mn) is equal to: 160 Gy («surface» of alveolar epithelium layer); 8.9 Gy («bottom» of alveolar epithelium layer, in a case minimal thickness of epithelium cells); 0.4 Gy («bottom» of alveolar epithelium (in a case maximal thickness of epithelium cells).

Conclusion

Absorbed dose (up to whole decay of ^{56}Mn) is equal to: 160 Gy («surface» of alveolar epithelium layer); 8.9 Gy («bottom» of alveolar epithelium layer, in a case minimal thickness of epithelium cells); 0.4 Gy («bottom» of alveolar epithelium (in a case maximal thickness of epithelium cells).

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В.Ф. Степаненко, К.Ш. Жумадилов, М. Хоши, Е.Т. Жунусов, С. Эндо, М. Отаки, К. Отани, Н. Фуджимото, К. Шичиджо, Н. Кавано, А. Сакагучи, Н.Ж. Чайжунусова, Д.М. Шабдарбаева, А. Бауыржан, В.С. Гныря, А.С. Азимханов, А.Д. Каприн, С.А. Иванов, Е. Яськова, И. Белуха, Т. Колыженков, А.Д. Петухов, В. Богачева

Егеуқұйрықтардың альвеолярлық эпителийіне ^{56}Mn ішкі әсері кезіндегі кеңістіктік микродеңгейде мөлшерінің таралуын алдын ала бағалау

Курчатов қаласындағы Байкал-1 реакторлық кешенінде (Курчатов қ., Шығыс Қазақстан облысы) радиациялық әсер эффектісін зерттеу бойынша эксперимент жүзінде ^{56}Mn ұнтағы тозаңының егеуқұйрықтарға әсерінің ішкі дозиметриялық зерттеуі жүргізілді. Бұл зерттеу Жапония, Қазақстан және Ресей Федерациясы ғалымдарының тобымен орындалды. Берілген жұмыста егеуқұйрықтар өкпесінің альвеолярлық эпителийін сәулелендіру дозасын бағалау нәтижелері көрсетілген. Эпителий «бетінде» жұтылған доза 160 г тең, эпителий жасушаларының «төменгі» минималды қалыңдығында жұтылған доза 8,9 г құрайды, ал эпителий жасушаларының максималды қалыңдығы үшін — 0,4 г.

Кілт сөздер: ішкі сәулелену, Курчатов, MCNP, егеуқұйрықтар, мүшелер, ^{56}Mn ұнтағы, эпителий қабаты, өкпе альвеоласы.

В.Ф. Степаненко, К.Ш. Жумадилов, М. Хоши, Е.Т. Жунусов, С. Эндо, М. Отаки, К. Отани, Н. Фуджимото, К. Шичиджо, Н. Кавано, А. Сакагучи, Н.Ж. Чайжунусова, Д.М. Шабдарбаева, А. Бауыржан, В.С. Гныря, А.С. Азимханов, А. Д. Каприн, С.А. Иванов, Е. Яськова, И. Белуха, Т. Колыженков, А.Д. Петухов, В. Богачева

Предварительная оценка пространственного распределения дозы на микроуровне при внутреннем воздействии ^{56}Mn на альвеолярный эпителий крыс

С целью изучения эффектов внутреннего облучения проведено специальное дозиметрическое исследование воздействия на экспериментальных крыс распыленным порошком массой ^{56}Mn. Все эксперименты проводились на реакторном комплексе «Байкал-1» (г. Курчатов, Восточно-Казахстанская область) после нейтронной активации стабильного порошка Mn. Данное исследование было проведено группой ученых из Японии, Казахстана и Российской Федерации. В настоящей работе приведены результаты оценки доз облучения альвеолярного эпителия легких крыс. Поглощенная доза на «поверхности» эпителия равна 160 г, а поглощенная доза в «дне» эпителия для минимальной толщины клеток эпителия составляет 8,9 г, а для максимальной толщины клеток эпителия — 0,4 г.

Ключевые слова: внутреннее облучение, Курчатов, MCNP, крысы, органы, порошок ^{56}Mn, слой эпителия, альвеолы легких.