

V.F. Stepanenko¹, K.Sh. Zhumadilov², M. Hoshi³, Y.T. Zhunussov⁴, S. Endo³, M. Ohtaki³, K. Otani³, N. Fujimoto³, K. Shichijo⁵, N. Kawano³, A. Sakaguchi⁶, N.Z. Chaizhunusova⁴, D.M. Shabdarbaeva⁴, A. Baurzhan⁴, V.S. Gnyrya⁷, A.S. Azimkhanov⁷, A.D. Kaprin¹, S.A. Ivanov¹, E. Yaskova¹, I. Belukha¹, T. Kolyzhenkov¹, A.D. Petukhov¹, V. Bogacheva¹

¹A. Tsyb MRRC – National Medical Research Center of Radiology, Ministry of Health, Obninsk, Russia;

²L.N. Gumilyov Eurasian National University, Nur-Sultan, Kazakhstan;

³Hiroshima University, 734-8553, Japan;

⁴Semey State Medical University, Kazakhstan;

⁵Nagasaki University, 1-12-4, Sakamoto, 852-8523, Japan;

⁶Graduate School of Pure and Applied Sciences, University of Tsukuba;

⁷National Nuclear Center of the Republic of Kazakhstan, Kurchatov, Kazakhstan

(E-mail: zhumadilovk@gmail.com)

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

Special dosimetry study of experimental rats exposure by sprayed ⁵⁶Mn 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 epithelium 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 ⁵⁶Mn, 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 ⁵⁶Mn ($T_{1/2}=2.58$ 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 ⁵⁶Mn in a form of powder sprayed over experimental rats was conducted recently [5]. Activation of MnO₂ (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 ⁵⁶Mn 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 ⁵⁶Mn (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 ⁵⁶MnO₂ microparticles (density of manganese dioxide is 5.03 g/cm³). Mean diameter of ⁵⁶MnO₂ microparticles is equal to 4 μm. The corresponding data of ⁵⁶Mn's Auger electrons, X-rays, beta particles < and gamma-rays are presented in Tables 1–3 and in Figure 1.

Irradiation of ⁵⁶Mn

Table 1

⁵⁶Mn: 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

⁵⁶Mn: 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)	

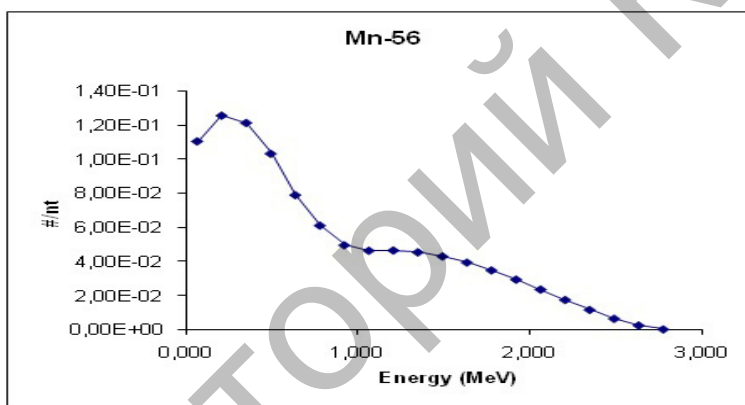


Figure 1. Beta particles of ⁵⁶Mn: intensity is 100 %, average energy is 829.21 keV (mean R99 is about 1.8 cm), and maximal energy is 2848.00 keV (maximal R99 is about 6 cm)

Table 3

⁵⁶Mn: 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 μm 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 ⁵⁶Mn microparticle.

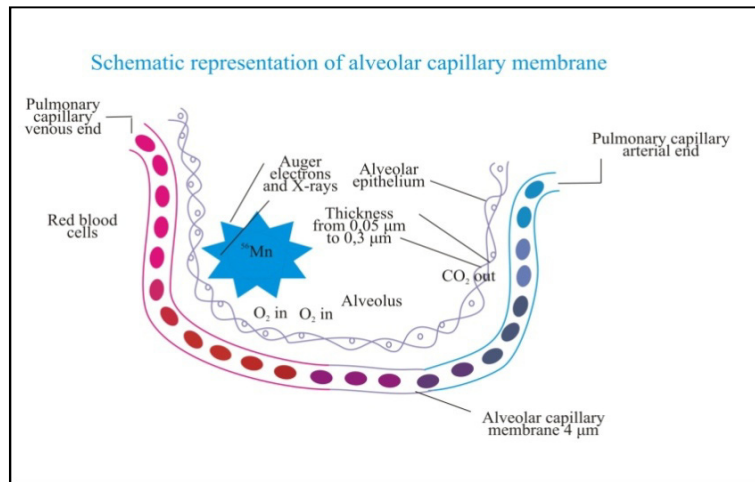


Figure 2. Schematic representation of lung's alveoli with $^{56}\text{MnO}_2$ microparticle.

Results and Discussion

It was estimated, that mean initial activity of one $^{56}\text{MnO}_2$ 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 = 9.288×10^3 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: $N = 0.196 \text{ Bq} \times 9.288 \times 10^3 \text{ seconds} / 0.693 = 2.627 \times 10^3$ 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.

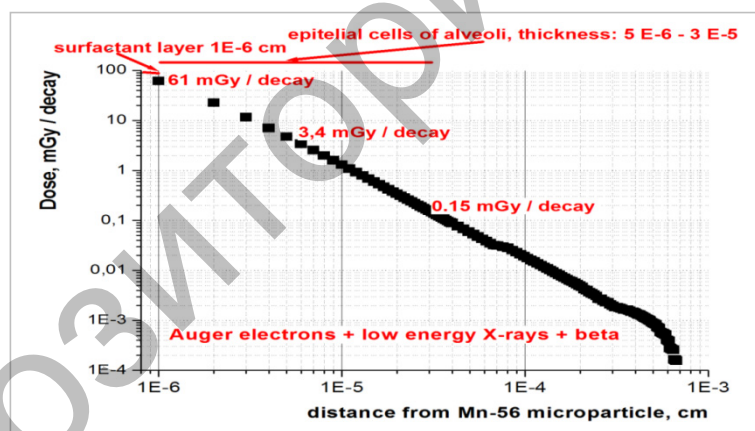


Figure 3. Results of calculations of spatial dose distribution around ^{56}Mn microparticle placed into biological tissue.

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} cm 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)).

The study was carried out with the financial support of the Semey State Medical University, Ministry of Health of the Republic of Kazakhstan (research support in the Republic of Kazakhstan). The research of specialists from Japan was supported by JSPS KAKENHI grants No. 26257501 and No. 24310044, Japan. This study was supported by MRRC named after A.F. Tsyb (equipment and MC calculations).

References

- 1 Yamamoto, M., Takada, T., Nagao, S., Koike, T., Shimada, K., Hoshi, M., & et al. (2012). An early survey of the radioactive contamination of soil due to the Fukushima Dai-ichi nuclear power plant accident, with emphasis on plutonium analysis. *Geochem J.*, 46, 341–353.
- 2 Zhumadilov, K., Ivannikov, A., Zharlyganova, D., Zhumadilov, Z., Stepanenko, V., Apsalikov, K., & et al. (2009). ESR dosimetry study on population of settlements nearby Ust-Kamenogorsk city, Kazakhstan. *Radiat. Environ. Biophys.* 48, 419–425.
- 3 Zhumadilov, K., Ivannikov, A., Stepanenko, V., Toyoda, S., Skvortsov, V., & Hoshi M. (2016). EPR Dosimetry study for population residing in the vicinity of fallout trace for nuclear test on 7 August 1962. *Radiat. Prot. Dosim. ISSN: 0144–8420.* 172 (1–3), 260–264.
- 4 Stepanenko, V.F., Hoshi M., Bailiff I.K., Ivannikov A.I., Toyoda S., Yamamoto M., & et al. (2006). Around Semipalatinsk nuclear test site: Progress of dose estimations relevant to the consequences of nuclear tests. *A summary of 3rd Dosimetry Workshop on the Semipalatinsk nuclear test site area, RIRBM, Hiroshima University, Hiroshima, 9–11 March, 2005. J. Radiat. Res.* 47, Suppl. A, A1–A13.
- 5 Hoshi, M., Ohtaki, M., Otani, K., Fujimoto, N., Shichijo, K., Endo, S., & et al. (2018). Our Semipalatinsk studies. -S1: Experimental and theoretical studies on biological effects of radioactive micro-particles, S2: Air dust sampling and measurements, S3: Dosimetry and risk studies in Semipalatinsk area. *21th Hiroshima International Symposium: Studies on health effects of exposure to radioactive micro-particles, January 23, Hiroshima (Japan).*
- 6 Stepanenko, V.F., Rakhypbekov, T.K., Kaprin, A.D., Ivanov, S.A., Otani, K., Endo, S., & et al. (2016). Irradiation of experimental animals by neutron activated dust: development and realization of the method — first results of international multicenter study. *Radiation and Risk*, 25, 111–125.
- 7 Stepanenko, V., Rakhypbekov, T., Otani, K., Endo, S., Satoh, K., Kawano, N., & et al. (2017). Internal exposure to neutron-activated ^{56}Mn dioxide powder in Wistar rats—Part 1: Dosimetry. *Radiat. Environ. Biophys. Vol. 56, Issue 1*, 47–54.
- 8 Shichijo, K., Fujimoto, N., Uzbekov, D., Kairkhanova, Y., Saimova, A., Chaizhunusova, N., & et al. (2017). Internal exposure to neutron-activated ^{56}Mn dioxide powder in Wistar rats – Part 2: pathological effects. *Radiat. Environ. Biophys.* 1 March 2017, Vol. 56, Issue 1, 55–61.
- 9 Shichijo, K., Fujimoto, N., Uzbekov, D., Kairkhanova, Y., Saimova, A., Chaizhunusova, N., & et al. (2017). Erratum to: Internal exposure to neutron-activated ^{56}Mn dioxide powder in Wistar rats — Part 2: pathological effects. *Radiat. Environ. Biophys.* 2017, Vol. 56, Issue 1, 203–204.
- 10 Ohtaki, M., Otani, K., Tonda, T., Sato, Y., Hara, N., Imori, S., & et al. (2014). Effect of distance from hypocenter at exposure on solid cancer mortality among Hiroshima atomic bomb survivors with very low initial radiation dose in the Dosimetry System 1986 (DS86). *Health Phys. V. 107, Suppl. 1*, 45.
- 11 Stepanenko, V., Hoshi, M., Endo, S., Ohtaki, M., Otani, K., Fujimoto, N., & et al. (2018). Calculations of dose distribution on the spatial microlevel around ^{56}Mn microparticles incorporated into biological tissue: preliminary results. *21th Hiroshima International Symposium: Studies on health effects of exposure to radioactive micro-particles, January 23, Hiroshima (Japan).*

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 эффектін 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.