

В. А. Курочкіна*, Т. В. Циганок

Інститут ядерних досліджень НАН України, Київ, Україна

*Відповідальний автор: knitel@ukr.net

**ОСОБЛИВОСТІ ВНУТРІШНЬОГО ОПРОМІНЕННЯ ЛЮДИНИ
ТА ПРОБЛЕМИ ЙОГО ДОЗИМЕТРІЇ.
II. СПЕЦИФІКА ТА МЕТОДИ БІОЛОГІЧНОЇ ДОЗИМЕТРІЇ**

Дана публікація є продовженням огляду про особливості та проблеми дозиметрії інкорпорованих радіонуклідів. У цій частині описано та обговорено специфіку та методи біологічної дозиметрії.

Ключові слова: інкорпоровані радіонукліди, біологічна дозиметрія, ^3H , ^{137}Cs , ^{131}I , ^{90}Sr , ^{239}Pu .

V. A. Kurochkina*, T. V. Tsyganok

Institute for Nuclear Research, National Academy of Sciences of Ukraine, Kyiv, Ukraine

*Corresponding author: knitel@ukr.net

**FEATURES OF INTERNAL HUMAN IRRADIATION AND PROBLEMS OF ITS DOSIMETRY.
II. SPECIFICITY AND METHODS OF BIOLOGICAL DOSIMETRY**

This publication is a continuation of the review on the features and problems of dosimetry of incorporated radionuclides. This part describes and discusses the specifics and methods of biological dosimetry.

Keywords: incorporated radionuclides, biological dosimetry, ^3H , ^{137}Cs , ^{131}I , ^{90}Sr , ^{239}Pu .

СПИСОК ВИКОРИСТАНОЇ ЛІТЕРАТУРИ / REFERENCES

1. M.A. Bender et al. Current status of cytogenetic procedures to detect and quantify previous exposures to radiation. *Mutat. Res.* 196(2) (1988) 103.
2. W.E. Bolch et al. (on behalf of ICRP). The ICRP computational framework for internal dose assessment for reference adults: Specific absorbed fractions. ICRP Publication 133. *Ann. ICRP* 45(2) (2016) 73 p.
3. International basic safety standards for protection against ionizing radiation and for the safety of radiation sources. Safety series No. 115 (Vienna, IAEA, 1996) 370 p.
4. A. Giussani et al. Eurados review of retrospective dosimetry techniques for internal exposures to ionising radiation and their applications. *Radiat. Environ. Biophys.* (59) (2020) 357.
5. *Cytogenetic Dosimetry: Applications in Preparedness for and Response to Radiation Emergencies* (Vienna, IAEA, 2011) 247 p.
6. H.M. Swartz, B.B. Williams, A.B. Flood. Overview of the principles and practice of biodosimetry. *Radiat. Environ. Biophys.* 53 (2014) 221.
7. D. Hladik et al. The potential of omics in biological dosimetry. *Radiation* 2 (2022) 78.
8. W. Sudprasert, O.V. Belyakov, S. Tashiro. Biological and internal dosimetry for radiation medicine: current status and future perspectives. *J. Radiat. Res.* 63(2) (2022) 247.
9. G.B. Curwen et al. mFISH analysis of chromosome aberrations induced *in vitro* by α -particle radiation: Examination of dose-response relationships. *Radiat. Res.* 178(5) (2012) 414.
10. E. Hammarlund et al. Duration of antiviral immunity after smallpox vaccination. *Nat. Med.* 9 (2003) 1131.
11. E.A. Ainsbury et al. What radiation dose does the FISH translocation assay measure in cases of incorporated radionuclides for the Southern Urals populations? *Radiat. Prot. Dosim.* 159(1-4) (2014) 26.
12. A. Balasem et al. Radiation-induced chromosomal aberrations in simulated internal contamination with radioactive caesium. *Radiat. Prot. Dosim.* 42(4) (1992) 323.
13. T.S. Gnanasekaran. Cytogenetic biological dosimetry assays: recent developments and updates. *Radiat. Oncol. J.* 39(3) (2021) 159.
14. A. Steinsträßer, W. Kemmer. Biophysical investigations of the dose-effect relationship in chromosome aberrations of human lymphocytes caused by Thorotrast deposits. I. Physical aspects. *Radiat. Environ. Biophys.* 19(1) (1981) 1.
15. A. Steinsträßer, W. Kemmer. Biophysical investigations of the dose-effect relationship in chromosome aberrations of human lymphocytes caused by Thorotrast deposits. II. Biological and medical aspects. *Radiat. Environ. Biophys.* 19(1) (1981) 17.
16. N. Vulpis. The induction of chromosome aberrations in human lymphocytes by *in vitro* irradiation with β particles from tritiated water. *Radiat. Res.* 97 (1984) 511.
17. G. Ribas. Genotoxicity of tritiated water in human lymphocytes. *Toxicol. Lett.* 70 (1994) 63.
18. K. Tanaka, S. Sawada, N. Kamada. Relative biological effectiveness and dose rate effect of tritiated water on chromosomes in human lymphocytes and bone marrow cells. *Mutat. Res. Lett.* 323 (1994) 53.

19. W. Deng et al. Biological dosimetry of beta-ray exposure from tritium using chromosome translocations in human lymphocytes analyzed by fluorescence in situ hybridization. *Radiat. Res.* 150 (1998) 400.
20. D.C. Lloyd et al. Accidental intake of tritiated water: A report of two cases. *Radiat. Prot. Dosim.* 15 (1986) 191.
21. D.C. Lloyd et al. Accidental intake of tritiated water: a cytogenetic follow-up case on translocation stability and dose reconstruction. *Int. J. Radiat. Biol.* 73 (1998) 543.
22. A.T. Ramalho, A.C.H. Nascimento, A.T. Natarajan. Dose assessments by cytogenetic analysis in the Goiania (Brazil) radiation accident. *Radiat. Prot. Dosim.* 25(2) (1988) 97.
23. A.T. Ramalho, A.C.H. Nascimento. The fate of chromosomal aberrations in ¹³⁷Cs-exposed individuals in the Goiania radiation accident. *Health Phys.* 60(1) (1991) 67.
24. A.T. Ramalho. *Subsídios to Cytogenetic Dosimetry Technique Generated from Analysis of Results of Goiania Radiological Accident. Thesis (Brazil, 1993) 136 p.* (Portuguese)
25. J.L. Lipsztein et al. The Goiânia ¹³⁷Cs accident - A review of the internal and cytogenetic dosimetry. *Radiat. Prot. Dosim.* 79 (1998) 149.
26. A.T. Natarajan et al. ¹³⁷Cesium-induced chromosome aberrations analyzed by fluorescence in situ hybridization: eight years follow-up of the Goiânia radiation accident victims. *Mutat. Res.* 400 (1998) 299.
27. D.R. Melo et al. ¹³⁷Cs internal contamination involving a Brazilian accident, and the efficacy of Prussian Blue treatment. *Health Phys.* 66 (1994) 245.
28. Recommendation of the International Commission on Radiological Protection. ICRP Publication 60. *Ann ICRP* 21(1-3) (1990) 211 p.
29. В.А. Курочкіна та ін. Хромосомні аберації у лімфоцитах людини за зовнішнього та/або внутрішнього опромінення зразків крові ¹³⁷Cs у модельних експериментах *in vitro*. *Ядерна фізика та енергетика* 22 (2021) 300. / V.A. Kurochkina et al. Chromosome aberrations in human lymphocytes due to external and/or internal irradiation of blood samples by ¹³⁷Cs in model experiments *in vitro*. *Nucl. Phys. At. Energy* 22 (2021) 300. (Ukr)
30. S. Roch-Lefèvre et al. A mouse model of cytogenetic analysis to evaluate caesium 137 radiation dose exposure and contamination level in lymphocytes. *Radiat. Environ. Biophys.* 55 (2016) 61.
31. N. Vulpis, G. Scarpa. Induction of chromosome aberrations by ⁹⁰Sr β-particles in cultured human lymphocytes. *Mutat. Res.* 63 (1986) 277.
32. E.M. de Oliveira et al. Evaluation of the effect of ⁹⁰Sr β-radiation on human blood cells by chromosome aberration and single cell gel electrophoresis (comet assay) analysis. *Mutat. Res.* 476 (2001) 109.
33. *Toxicological Profile for Iodine (Atlanta: Agency for Toxic Substances and Disease Registry 2004) 580 p.*
34. M.G. Stabin. OLINDA/EXM 2 - The next-generation personal computer software for internal dose assessment in nuclear medicine. *Health Phys.* 124(5) (2023) 397.
35. A. Ozdal et al. Evaluation of the physical and biological dosimetry methods in iodine-131-treated patients. *World J. Nucl. Med.* 17 (2018) 253.
<https://pmc.ncbi.nlm.nih.gov/articles/PMC6216729>
36. M.A. Monsieurs et al. Estimation of risk based on biological dosimetry for patients treated with radioiodine. *Nucl. Med. Commun.* 20(1999) 911.
37. U. Eberlein et al. Calibration of the γ-H2AX DNA double strand break focus assay for internal radiation exposure of blood lymphocytes. *PLoS One* 10(4) (2015) e0123174.
38. S. Roch-Lefèvre et al. Cytogenetic assessment of heterogeneous radiation doses in cancer patients treated with fractionated radiotherapy. *Br. J. Radiol.* 83(993) (2010) 759.
39. M. Bauchinger et al. FISH-based analysis of stable translocations in a Techa River population. *Int. J. Radiat. Biol.* 73(6) (1998) 605.
40. A.V. Vozilova et al. Preliminary FISH-based assessment of external dose for residents exposed on the Techa River. *Radiat. Res.* 177(1) (2011) 84.
41. N. Watanabe et al. Radiotoxicity after strontium-89 therapy for bone metastases using the micronucleus assay. *J. Nucl. Med.* 39 (1998) 2077.
42. Age-Dependent Doses to Members of the Public from Intake of Radionuclides: Part 2. Ingestion Dose Coefficients. ICRP Publication 67. *Ann. ICRP* 23(3-4) (1993) 164 p.
43. E.J. Tawn, C.A. Whitehouse, A.E. Riddell. FISH chromosome analysis of plutonium workers from the Sellafield Nuclear Facility. *Radiat. Res.* 165 (2006) 592.
44. J.F. Barquinero, G. Stephan, E. Schmid. Effect of americium-241 α-particles on the dose-response of chromosome aberrations in human lymphocytes analysed by fluorescence *in situ* hybridization. *Int. J. Radiat. Biol.* 80 (2004) 155.
45. W.J.F. Standring, M. Dowdall, P. Strand. Overview of dose assessment developments and the health of riverside residents close to the “Mayak” PA Facilities, Russia. *Int. J. Environ. Res. Public Health* 6 (2009) 174.
46. Т.В. Цыганок, Л.К. Бездробная. «Нагруженные» хромосомными аберрациями клетки в культуре лимфоцитов периферической крови человека и их анализ у самоселов Зоны отчуждения ЧАЭС. *Ядерна фізика та енергетика* 3(11) 2003 147. / T.V. Tsyganok, L.K. Bezdobnaya. The “rouge” cells in cultured human peripheral blood lymphocytes and their analysis in ChNPP exclusion zone self-settlers. *Nucl. Phys. At. Energy* 3(11) 2003 147. (Rus)

47. Л.К. Бездробная и др. Показатели состояния генома крови персонала объекта «Укрытие». [Проблеми Чорнобиля 10\(2\) \(2002\) 307.](#) / L.K. Bezdrobnaia et al. Indicators of the genome status in the blood of the Shelter Object personnel. [Problemy Chornobylia 10\(2\) \(2002\) 307.](#) (Rus)
48. R.M. Anderson et al. Increased complexity of radiation-induced chromosome aberrations consistent with a mechanism of sequential formation. [Cytogenet. Genome Res. 112 \(2006\) 35.](#)
49. G.B. Curwen et al. Chromosome aberrations in workers with exposure to α -particle radiation from internal deposits of plutonium: expectations from in vitro studies and comparisons with workers with predominantly external γ -radiation exposure. [Radiat. Environ. Biophys. 54 \(2015\) 195.](#)
50. E.J. Tawn et al. Chromosome aberrations determined by sFISH and G-banding in lymphocytes from workers with internal deposits of plutonium. [Int. J. Radiat. Biol. 92\(6\) \(2016\) 312.](#)
51. M.P. Hande et al. Past exposure to densely ionizing radiation leaves a unique permanent signature in the genome. [Am. J. Hum. Genet. 72 \(2003\) 1162.](#)
52. C.R. Mitchell et al. Stable intrachromosomal biomarkers of past exposure to densely ionizing radiation in several chromosomes of exposed individuals. [Radiat. Res. 162\(3\) \(2004\) 257.](#)
53. E.J. Tawn et al. The characterization and transmissibility of chromosome aberrations induced in peripheral blood lymphocytes by *in vitro* alpha-particle radiation. [Radiat. Res. 168 \(2007\) 666.](#)

Надійшла / Received 05.08.2025