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## TOTAL MORTALITY DYNAMICS OF THE POPULATION OF THE ABAY AND BESKARAGAI DISTRICTS EXPOSED TO RADIATION AS A RESULT OF NUCLEAR WEAPONS TESTS (1949-1975)

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### Abstract

**Introduction.** Mortality rates are an indicator of population health in various countries worldwide. They are influenced by sociodemographic factors, the state of the healthcare system, and environmental factors, including exposure to ionizing radiation.

**The aim** of our study is to analyze mortality rates in the Abay and Beskaragay districts of the Abay region exposed to radiation as a result of nuclear weapons testing from 1949 to 1975.

**Materials and Methods.** The study data consisted of cause-of-mortality certificates for the population of three districts in the region from 1949 to 1975. The population of two districts (Abay and Beskaragay) was exposed to effective equivalent doses of 625 to 870 mSv. The comparison group consisted of residents of the Kokpekty district. A total of 16,348 cause-of-mortality certificates were copied and analyzed. Effective equivalent doses of radiation exposure for the population of the study areas were obtained from the State Scientific Automated Medical Registry database.

**Results.** A significant increase in overall mortality rates for the population of all age groups in the Beskaragay district of the Abay region was found 4-21 years after the onset of irradiation compared to the rates in the control Kokpekty district. No significant differences were found in overall mortality rates in the Abay district compared to the control group. A modifying effect of age on overall mortality rates was established for the population of the exposed groups. In subsequent years (26-49 years after the onset of irradiation), 6 to 8 peaks of significantly higher overall mortality rates were recorded among men and women in the Beskaragay district compared to the control group. Among men and women in the Abay district, the overall mortality rate did not differ significantly from the control group.

**Conclusion.** The overall mortality curve was remittent, with significant peaks alternating with plateaus in some years. No dose-response relationship was found for overall mortality rates in the study areas.

**Key words:** total mortality, radiation exposure, effective equivalent doses of radiation, population.

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### Резюме

## ДИНАМИКА ОБЩЕЙ СМЕРТНОСТИ НАСЕЛЕНИЯ РАЙОНОВ АБАЙ И БЕСКАРАГАЙ, ПОДВЕРГШЕГОСЯ ОБЛУЧЕНИЮ В РЕЗУЛЬТАТЕ ИСПЫТАНИЙ ЯДЕРНОГО ОРУЖИЯ (1949-1975 ГГ.)

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**Введение.** Показатели смертности являются индикатором состояния здоровья населения различных стран мира. На них оказывают влияние социально-демографические факторы, состояние системы здравоохранения страны проживания, а также экологические факторы, к которым относится воздействие ионизирующей радиации.

**Целью** нашего исследования является анализ показателей смертности населения Абайского и Бескарагайского районов области Абай, подвергшихся радиационному воздействию вследствие испытаний ядерного оружия, за период с 1949 по 1975 гг.

**Материалы и методы.** Материалами исследования послужили акты-сертификаты причин смертности населения трех районов области за период с 1949 по 1975 гг. Население двух районов (Абайского и Бескарагайского,) подвергалось облучению в диапазоне эффективных эквивалентных доз 625 - 870 мЗв. Группа сравнения была представлена населением Кокпектинского района. Выкопировано и проанализировано 16 348 актов- сертификатов причин смертности. Эффективные эквивалентные дозы облучения населения исследуемых районов были взяты из базы данных Государственного научного автоматизированного медицинского регистра.

**Результаты.** Установлено достоверное увеличение коэффициентов общей смертности населения всех возрастных групп Бескарагайского района области Абай через 4-21 год от начала облучения по сравнению с показателями контрольного Кокпектинского района. Не обнаружено существенных различий в уровнях общей смертности населения Абайского района по сравнению с контрольной группой. Установлено модифицирующее влияние на показатели общей смертности возраста населения экспонированных групп. В последующие годы (26-49 лет от начала облучения) среди мужчин и женщин Бескарагайского района зарегистрировано от 6 до 8 пиков существенного превышения уровня общей смертности по сравнению с показателями контроля. Среди мужчин и женщин Абайского района уровень общей смертности среди мужчин и женщин существенно не отличался от показателей контроля.

**Заключение.** Кривая уровня общей смертности носила ремитирующий характер с чередованием существенных подъемов с последующей нивелировкой в отдельные годы. Не установлено закономерностей «доза-эффект» для показателей общей смертности населения изучаемых районов.

**Ключевые слова:** общая смертность, радиационное воздействие, эффективные эквивалентные дозы облучения, население.

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Түйіндеме

## **ЯДРОЛЫҚ ҚАРУДЫ СЫНАУ НӘТИЖЕСІНДЕ СӘУЛЕЛЕНУГЕ ҰШЫРАҒАН АБАЙ ЖӘНЕ БЕСҚАРАҒАЙ АУДАНДАРЫ ХАЛҚЫНЫҢ ЖАЛПЫ ӨЛІМ-ЖІТІМІНІҢ ДИНАМИКАСЫ (1949-1975 ЖЖ.)**

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**Кіріспе.** Өлім-жітім көрсеткіштері әлемнің әртүрлі елдеріндегі халық денсаулығының жай-күйін сипаттайтын маңызды индикатор болып табылады. Өлім-жітім деңгейіне әлеуметтік-демографиялық факторлар, тұрғылықты елдің денсаулық сақтау жүйесінің жағдайы, сондай-ақ экологиялық факторлар, соның ішінде иондаушы сәулеленудің әсері ықпал етеді.

**Зерттеудің мақсаты** — ядролық қаруды сынау нәтижесінде радиациялық әсерге ұшыраған Абай облысының Абай және Бесқарағай аудандары халқының 1949–1975 жылдар аралығындағы өлім-жітім көрсеткіштерін талдау.

**Материалдар мен әдістер.** Зерттеу материалдары ретінде 1949–1975 жылдар аралығындағы облыстың үш ауданы халқының өлім себептері жөніндегі акт-сертификаттар пайдаланылды. Абай және Бесқарағай аудандарының халқы тиімді эквиваленттік сәулелену дозаларының 625–870 мЗв диапазонында сәулеленуге

ұшыраған. Салыстыру тобы ретінде Көкпекті ауданының халқы алынды. Барлығы 16 348 өлім себептері жөніндегі акт-сертификат көшіріліп, талданды. Зерттелген аудандар халқының тиімді эквиваленттік сәулелену дозалары туралы мәліметтер мемлекеттік ғылыми автоматтандырылған медициналық регистрдің деректер базасынан алынды.

**Нәтижелер.** Сәулелену басталғаннан кейін 4–21 жыл аралығында Абай облысының Бесқарағай ауданында барлық жас топтарындағы халықтың жалпы өлім-жітім коэффициенттерінің бақылау тобы болып табылатын Көкпекті ауданының көрсеткіштерімен салыстырғанда сенімді түрде жоғарылағаны анықталды. Абай ауданы халқының жалпы өлім-жітім деңгейі бақылау тобымен салыстырғанда елеулі айырмашылықтар көрсетпеді. Экспонирленген топтарда жас ерекшелігінің жалпы өлім-жітім көрсеткіштеріне модификациялаушы әсері анықталды. Кейінгі жылдары (сәулелену басталғаннан кейін 26–49 жыл) Бесқарағай ауданында ерлер мен әйелдер арасында жалпы өлім-жітім деңгейінің бақылау көрсеткіштерінен 6–8 рет айқын арту шектері тіркелді. Абай ауданында ерлер мен әйелдердің жалпы өлім-жітім деңгейі бақылау тобынан елеулі түрде ерекшеленбеді.

**Қорытынды.** Жалпы өлім-жітім деңгейінің динамикасы толқын тәрізді сипатта болып, айқын жоғарылаулар мен кейінгі жылдардағы көрсеткіштердің тегістелуі кезектесіп отырды. Зерттелген аудандар халқының жалпы өлім-жітім көрсеткіштері үшін «доза-әсер» типіндегі айқын заңдылықтар анықталған жоқ.

**Түйінді сөздер:** жалпы өлім-жітім, радиациялық әсер, тиімді эквиваленттік сәулелену дозалары, халық.

#### Дәйексөз үшін:

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#### Introduction

Mortality rates from various causes, primarily from oncological diseases and diseases of the circulatory system, as well as overall mortality, are indicators of the health status of the population in various countries around the world. These indicators are influenced by socio-demographic factors, such as the level of national income, the state of the healthcare system in the country of residence, the age structure of the population, the level of education of the population, nutrition, as well as environmental factors. One of such environmental risk factors for residents of some areas of the Abay region (former Semipalatinsk region) over a long period of time, starting in 1949, is exposure to ionizing radiation in the range of medium and low doses. During the testing period at the Semipalatinsk nuclear test site from 1949 to 1989, 468 nuclear charges were detonated, including 117 ground and air explosions. As a result of the tests, hundreds of thousands of residents of the territories adjacent to the test site, including several generations, were exposed to repeated external and internal irradiation [8, 14]. Undoubtedly, exposure to ionizing radiation had a negative impact on the health of the exposed population.

**The aim of our study** is to analyze mortality rates of the population of the Abay and Beskaragay districts of the Abay region, exposed to radiation as a result of nuclear weapons testing, for the period from 1949 to 1975.

#### Materials and Methods

##### *Characteristics of the Study Population*

The study was conducted using death certificates for the causes of death in three districts of the Abay region from 1949 to 1975. The population of two districts (Abay and Beskaragay) was exposed to effective equivalent doses of 625 to 870 mSv. The comparison group consisted of the population of the Kokpekty district and was adequate in

terms of size, age, and sex composition; residents of this district were virtually not exposed to radiation (effective equivalent doses ranged from 50 to 70 mSv).

Data from cause-of-mortality reports were entered into the State Scientific Automated Medical Registry (SSAMR) database, which contains information on individuals directly exposed to ionizing radiation as a result of nuclear weapons testing at the Semipalatinsk nuclear test site, as well as their subsequent generations. In addition, for each registry member, information is available on the calculated individual equivalent dose of radiation, health status, the presence of chronic diseases, causes of death, and the presence of radiation and non-radiation health risk factors. This information is necessary for the development of strategies aimed at preserving and improving the health of residents affected by the test site's activities. The registry was created in 2002 in collaboration with Japanese colleagues from the Radiation Effect Research Foundation and with the support of the Ministry of Health of the Republic of Kazakhstan [1,6].

Over the entire study period, male represented an average of 46.9% of the population in the districts studied, while female accounted for 53.1%. The population of the Abay district varied from 12,000 to 18,000 people, while the Abay and Kokpekty districts had a population of 24,000 to 32,000 people. Kazakhs predominated in the Abay and Kokpekty districts, while Caucasians (Russians and Ukrainians) predominated in the Beskaragay district. The age groups from 0 to 19 years constituted an average of 46%. From 1949 to 1975, 16,348 death certificates were copied and analyzed (Table 1). Causes of death were coded according to the Statistical Classification of Diseases, Injuries, and Causes of Death, 10th Revision (ICD-10), indicating the underlying disease that led to death.

Table 1.

Number of acts of causes of death in the studied areas (1949-1975, absolute numbers).

District	Male	Female	Total
Abay	1 825	1 560	3 386
Beskaragaysky	3 690	3 099	6 789
Kokpekty	3 280	2 893	6 173

Effective equivalent doses to the population of the study areas were selected from the State Scientific Automated Medical Registry database. The dose calculations are based on a joint US-Russian dose reconstruction

methodology developed based on the combined experience of experts from various countries [4, 5, 12, 15]. The characteristics of the effective equivalent doses to the population of the study areas are presented in Table 2.

Table 2.

Characteristics of average effective equivalent doses of radiation to the population of the studied areas.

District	External irradiation dose, mGy	Internal radiation dose, mSv	Effective equivalent dose, mSv
Abay	355,0	270,0	624,0
Beskaragaysky	670,0	200,0	870,0
Kokpekty			50,0-70,0*

*Statistical Analysis*

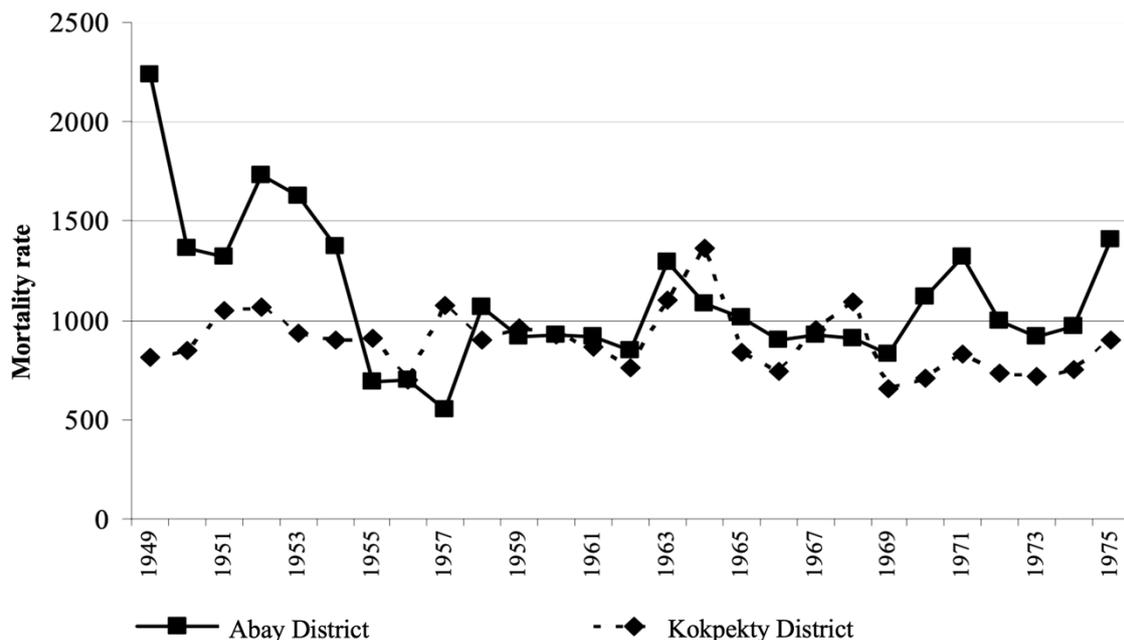
Statistical data processing was performed using SPSS (v.20) and Jamovi (v.2.5). Mortality rates per 100,000 population were calculated and subsequently standardized (ASR). Standardized mortality ratios (SMRs) were calculated. It was taken into account that the comparison group (residents of the Kokpekty district) corresponded in age structure to the entire population of men and women exposed to radiation. Mortality analysis was conducted by time period (1949–1975, 1975–1997). The level of statistical significance was set at  $p < 0.05$ .

**Results**

An analysis of the obtained study results showed that overall and oncological mortality rates for male and female of different age groups in some cases had significant

differences in dynamics between the exposed and control groups. Therefore, the analysis of mortality rates was conducted separately for men and women and for different age and sex groups. Among both male and female, the age-standardized overall mortality rates (ASR) for the population of the Abay district did not differ significantly from the control rates over the entire study period. The mortality rate fluctuated within a small range, averaging 580.2–1250.3 per 100,000 population (Figure 1). It should be noted that in the baseline period (1949–1952), due to high infant and child mortality, as well as tuberculosis mortality among the adult population, overall mortality rates in the Abay district were quite high and averaged 1100–2400 per 100,000 population.

**A) Male, 1949-1975**



B) Female, 1949-1975.

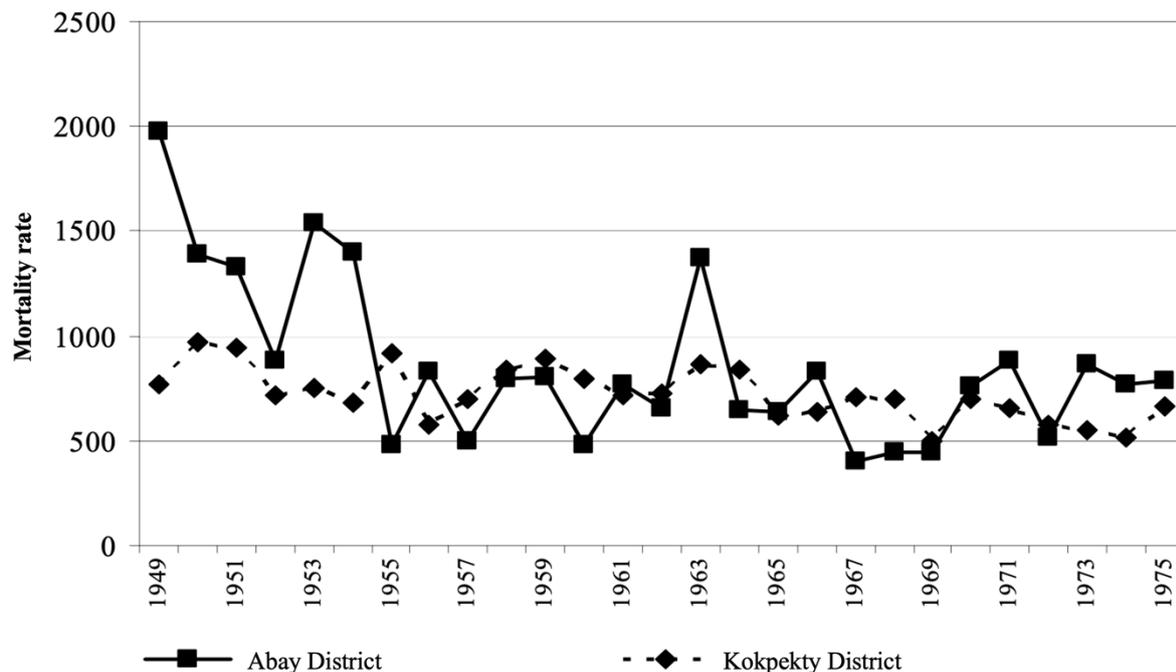
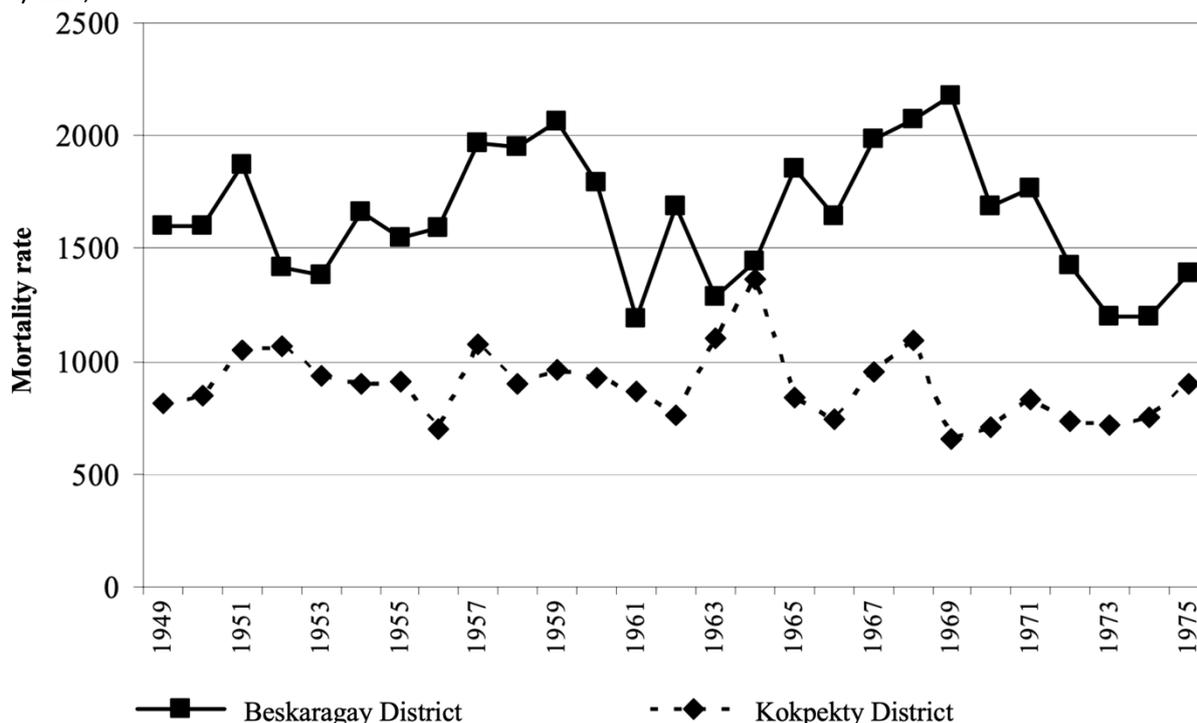


Figure 1. Mortality rates (ASR) in the residents of the Abay and Kokpekty districts.

Positive dynamics of standardized overall mortality rates among male and female was established among residents of the Beskaragay district in certain time intervals. Thus, among women of the Beskaragay district, due to increased infant and child mortality in the initial period, the overall mortality rate was significantly higher than in the control district. Beginning in 1955 (5 years after irradiation), the standardized overall mortality rate among female of the Beskaragay district increased significantly. Thus, in 1957 it was 1306.9 (1096.7-1557.5) per 100,000 population, in the control district – 697.0 (570.5-851.6)

per 100,000 population ( $P < 0.05$ ;  $SMR = 187\%$ ). By 1963-1964, the ASR in the exposed district leveled out with the control rate. Since 1965, another significant increase in ASR was recorded in the Beskaragay district - 1285.7 (1087.1-1520.5) per 100,000 population, in the control district - 621.7 (509.3-758.7) per 100,000 population ( $SMR = 207\%$ ). In 1971, the ASR of the exposed group was 1655.6 (1430.0-1916.8) per 100,000 population, in the control district - 547.7 (447.5-670.9) per 100,000 population ( $P < 0.01$ ;  $SMR = 180\%$ ) (Figure 2).

A) Male, 1949-1975.



B) Female, 1949-1975

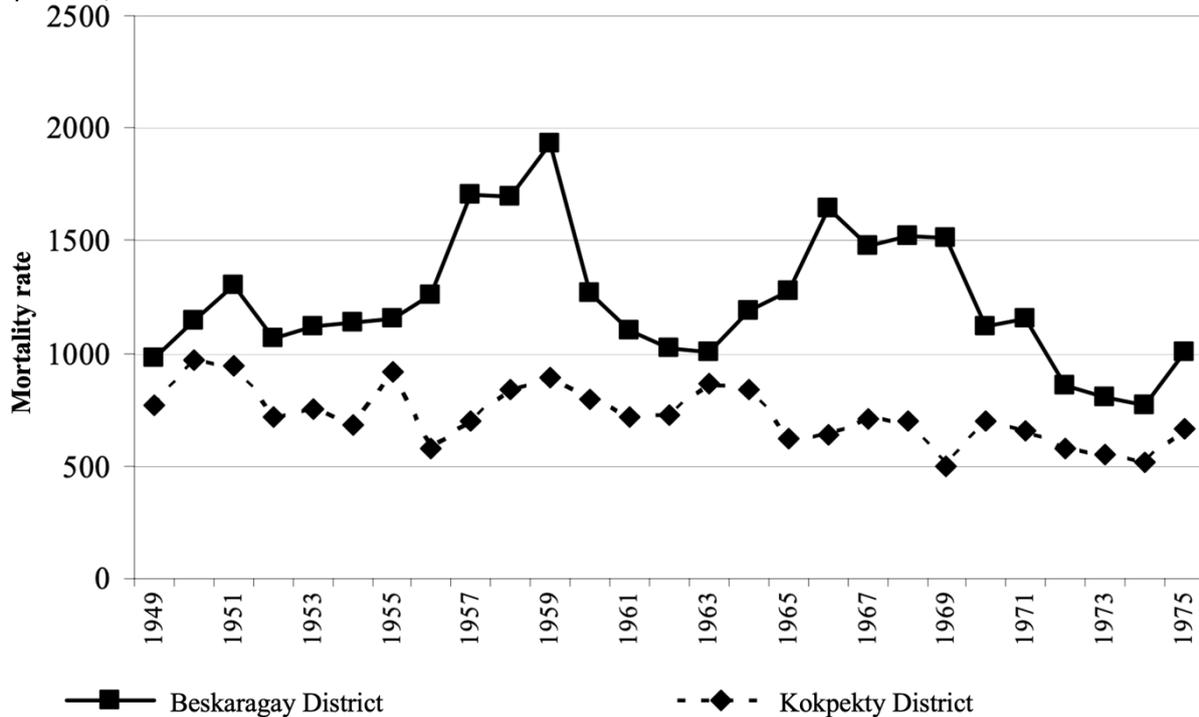


Figure 2. Mortality rates (ASR) in the residents of the Beskaragay and Kokpekty districts

Among male in the Beskaragay district, standardized overall mortality rates significantly exceeded those in the control district throughout almost the entire study period. Three time periods with significant increases in ASR rates were recorded: from 1952 (2 years after the start of exposure) to 1962 (12 years after the start of exposure); from 1965 (15 years after the start of exposure) to 1968 (18 years after exposure); from 1969 (19 years after exposure) to 1975 (25 years after the start of exposure). In 1957, the ASR in the exposed area was 1677.6 (1411.2-1985.7) per 100,000 population, in the control district- 910.8 (758.6-1093.0) per 100,000 population ( $P < 0.05$ ; SMR = 210%); in 1960 - 2068.5 (1810.7-2363.1) per 100,000 population, in the control district- 718.5 (597.8- 863.5) per 100,000 population ( $P < 0.01$ ; SMR = 290%) (Figure 2).

Thus, analysis of standardized overall mortality rates among the populations of the exposed and control areas revealed significant fluctuations depending on the temporal distribution and gender of individuals in the study groups. No modifying effect of radiation dose on changes in ASR rates was detected. For example, among the population exposed to an average dose of 625 mSv (Abay district), no significant differences in ASR were found compared to the control group. In another case, with exposure to an average dose of 870 mSv (Beskaragay district), significant excesses in standardized overall mortality rates were found at various time intervals after exposure compared to control rates.

**Discussion**

A retrospective assessment (1949-1998) of the overall mortality rate of the population of the Abay and Beskaragay districts of the Semipalatinsk region exposed to radiation allowed us to identify the characteristics and patterns of influence of the main modifying factors (dose magnitude and type of exposure, gender, age, time at risk) on

significant changes in mortality levels and structure. Preliminary processing of the study results revealed the lowest overall mortality rate among the population of the control Kokpekty district throughout the entire period compared to those in other districts.

Among the exposed districts, the lowest overall mortality rates, not significantly different from the control rates, were recorded among the population of the Abay district (weighted average cumulative effective equivalent dose of radiation to the population of 624.0 mSv).

An analysis of standardized overall mortality rates for the populations of exposed and control areas revealed significant fluctuations depending on the temporal distribution and gender of individuals in the study groups. No modifying effect of radiation dose on changes in ASR rates was detected. We believe that most of our calculations for reconstructing effective equivalent radiation doses are rather arbitrary and subject to a certain degree of error. The dose range established for the population of specific areas can be classified as low and medium radiation doses. Its variations within a range of up to 870 mSv significantly reduce the ability to determine sensitivity thresholds for certain excess somatic and oncological diseases that cause death. The insignificant variation in minimum and maximum radiation doses in specific areas complicates the identification of dose-response relationships for the dynamics of excess somatic diseases, taking into account their temporal distribution.

In our radiation-epidemiological analysis of the study results, we assumed that there can be no single cause for the increase or decrease in overall mortality rates, even with such a significant excess as ionizing radiation. The polymorphism of causes of overall mortality in population groups of any size and ethnic composition determines its level at any time, and is

dependent on modifying factors such as gender, age, and a combination of endogenous and exogenous factors.

At present, despite a significant number of publications, the somatic effects of exposure to ionizing radiation on the human body remain the least studied [3]. Early reports on the life expectancy of bombing survivors noted the absence of increased mortality from diseases not caused by neoplasms; they even revealed a lower level compared to the control cohort [13]. The situation changed with the accumulation of data on the Life Span Study cohort [16]. For 1958-1990, the relative risk (RR) of myocardial infarction for both sexes at a radiation dose of 1 Gy compared to the control cohort was 1.17. The highest risk was characteristic of individuals irradiated before the age of 40 years. Moreover, no dependence on gender or time elapsed since the bombing was found [11]. There is an association with radiation exposure of such manifestations of atherosclerosis as stroke and isolated systolic hypertension [7]. However, in terms of significance as a risk factor, radiation is inferior to such well-known factors as lifestyle and hypertension.

A study of mortality among atomic bomb survivors revealed a statistically significant increase in non-oncologic mortality rates depending on the radiation dose. Data were summarized for 86,572 atomic bomb survivors [13]. Of these, 27,000 non-oncologic mortality cases were registered, which occurred in the cohort from October 1, 1950, to December 31, 1990 [10]. A clear dose-response relationship was found in the excess of diseases such as cardiovascular, respiratory, and gastrointestinal tract diseases. The incidence of the above-mentioned diseases increased with increasing dose. An assessment of radiation-related non-oncologic mortality in the cohort showed that these diseases account for 50-100% of the number of solid cancers. However, these data did not explain the dose-response relationship [2]. No evidence was obtained against a linear relationship, but statistically consistent indicators with curvilinear dose-response functions demonstrate zero risk for doses below 0.5 Sv. The authors believe that the obtained data on reliable changes in the excess relative risk depending on age and exposure allow us to consider the dependence on these factors statistically insignificant. At the same time, a significant dependence on the dose level on the mortality rate from blood diseases with an excess relative risk several times greater than that for solid cancers was established [2].

Somewhat different results were obtained in a radiation-epidemiological analysis of non-oncologic morbidity among Chernobyl accident liquidators [9, 10]. The data were obtained from a cohort of 68,309 liquidators with verified medical data. It was established that, of all classes of non-oncologic diseases, statistically significant radiation risks were recorded in the first 3 years only for cerebrovascular diseases ( $ERR\ Gy(-1)=1.17$  at a 95% confidence interval of (0.45; 1.88)).

#### **Conclusion**

A significant increase in overall mortality rates was observed in all age groups of the Beskaragay district of the Abay region 4-21 years after the onset of irradiation compared to the control Kokpekty district. No significant differences were found in overall mortality rates in the exposed Abay district compared to the control district. A

modifying effect of age on overall mortality rates was established for the population of the exposed districts.

In subsequent years (26-49 years after the onset of irradiation), six to eight peaks of significantly higher overall mortality rates were recorded among men and women in the Beskaragay district compared to control rates. Among men and women in the Abay district, the overall mortality rate did not differ significantly from the control rates. The overall mortality curve was remitting, with alternating significant increases followed by a plateau in some years.

No dose-response relationships were found for overall mortality rates in the studied districts.

**Informed consent statement.** Not applicable.

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