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Long-Term Health Effects of Nuclear Tests: The Semipalatinsk Case

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Long-Term Health Effects of Nuclear Tests: The Semipalatinsk Case*

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Abstract

Using the Semipalatinsk Test Site in Kazakhstan, where about 456 nuclear tests occurred between 1949 and 1989, this paper examines the long-term health and well-being impacts of sustained radiation exposure. Results show that nuclear exposure significantly increases the risk of chronic disease and anemia, reduces subjective health, and lowers life satisfaction, with higher exposure intensities amplifying these effects. Older cohorts who, since early age, have been exposed to atmospheric testing face the greatest risks. These findings highlight the multigenerational health impacts of repeated radiation exposure, offering critical insights for public and health policy.

Keywords: Health, life satisfaction, nuclear tests explosions, environment
JEL: J24, H00, Q50, Q53

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1 Introduction

A key challenge in the study of economic development lies in understanding how repeated shocks—particularly those involving environmental and health risks—affect long-term human capital and economic outcomes. While economists have examined the impacts of conflict, pollution, and disease - showing that relatively mild shocks in early life can have substantial negative effects (Almond et al., 2009; Arpino et al., 2022; Chen, 2025) - the long-term effects of repeated radiation exposure remain uniquely challenging to measure and assess. Unlike pollution, whose effects often manifest gradually and vary in intensity, radiation exposure is far more hazardous due to its severe and typically irreversible health consequences. Invisible and enduring risks such as cancer and genetic damage make radiation an especially dangerous public health threat. Furthermore, the rarity of quasi-experimental settings involving unintentional population exposure complicates efforts to study its long term and multigenerational effects.

The Semipalatinsk (now Semey) Test Site in Kazakhstan, a former nuclear testing ground, provides a rare opportunity to explore the extreme and lasting impacts of repeated radiation exposure, offering insights that surpass those of most other events. With 456 nuclear explosions conducted between 1949 and 1989, the Semipalatinsk Test Site stands as one of the most heavily irradiated regions in the world. This exceptional setting allows for an in-depth examination of how such severe and persistent shocks affect health and economic well-being over time. Specifically, we leverage this context to investigate how early-life exposure, from in-utero to childhood, affects women's health later in life, as well as the subjective well-being of both women and men.

Using two nationally representative datasets—the Kazakhstan Demographic and Health Survey (KDHS) and the Life in Transition Survey (LiTS)—merged with detailed data on nuclear explosions, we analyze the effects of repeated nuclear exposure on various individual outcomes, including physical health (specifically chronic disease and anemia), subjective health perceptions, and life satisfaction. Results show that exposure to nuclear explosions is strongly associated with increased risks of chronic disease and anemia, as well as lower subjective health and life satisfaction. The intensity of exposure plays a significant role, with higher exposure correlating with greater health detriments. Older individuals, especially those born during the period of atmospheric nuclear tests (1945–1962), face the highest health and well-being risks due to cumulative exposure effects. This group consistently reports worse health outcomes and lower life satisfaction compared to younger cohorts. Patterns of mobility, such as whether individuals stayed in or moved to/out exposed areas, significantly influence subjective health and life satisfaction outcomes, underscoring the complex interplay between exposure, adaptation, and resilience. Because existing databases only provide respondents' locations at the oblast (region) level rather than at a more granular scale, our analysis focuses on the Semipalatinsk oblast, where the nuclear test site was located, as the primary treatment region. Despite this limitation, the analysis successfully captures statistically significant health impacts—both objective and subjective—resulting from over 40 years of nuclear explosions on the population. This approach remains important because nuclear exposure is not confined to the immediate vicinity of test sites but can be carried over broader areas by wind and other environmental factors, making a regional-level focus both logical and effective for assessing the widespread impacts of the cumulative exposure.

Our analysis contributes to the literature examining the effects of nuclear accidents on various outcomes, including physical and subjective health (Lehman and Wadsworth, 2011; Becker et al., 2022), mental health and life satisfaction (Danzer and Danzer, 2016), cognitive performance (Elsner and Wozny, 2023), and labor market outcomes (Lehman and Wadsworth, 2011). It also extends to studies investigating the impact of in-utero exposure to nuclear weapons tests (Black et al., 2019). Unlike previous research, which primarily focuses on the effects of isolated incidents, our study examines a unique context where a large population who from early age was repeatedly exposed to nuclear radiation over over four decades.

Second, our results on subjective well-being contribute to expand the limited research on the long-term effects of nuclear exposure on subjective well-being. Danzer and Danzer (2016) examined the impact of the Chernobyl disaster on life satisfaction in Ukraine 20 years after the event. Lehman and Wadsworth (2011) examine the link between current self-reported health and earlier Chernobyl-related radiation exposure. Our study adds to this literature by exploring the long-term effects of repeated nuclear exposure in Kazakhstan.

Third, our paper contributes to the understanding of the long-term health consequences of nuclear testing at the Semipalatinsk Nuclear Test Site. Apart from Becker et al. (2022), this is the only other paper which explores the long-run health effects of radiation exposure. There are various scientific and epidemiological studies describing and reporting incidences of cancer, lung diseases, tuberculosis in those living close proximity to the site and chromosomal translocations and congenital birth defect in their descendants.[1] But these studies are often just descriptive by nature and focus on the immediate outcomes of a selected sample of the population.

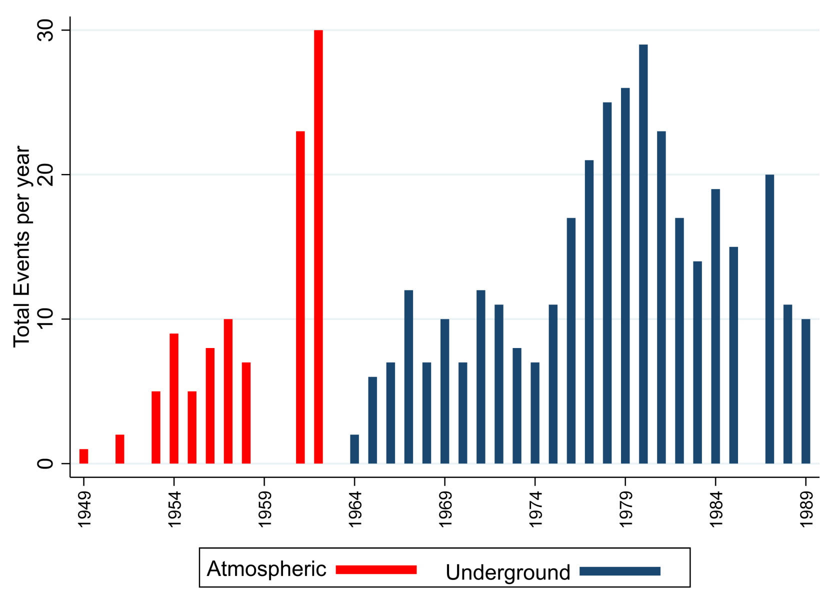
The insights gained from our study can inform public policy and health strategies for managing long-term health risks in populations exposed to radiation, whether from nuclear testing, accidents, or other sources and can help identify ways to mitigate risk of the impacts on socio-economic and wellbeing of exposed populations. The remainder of the paper is organized as follows. Section 2 provides background, Section 3 outlines the data, while Section 4 discusses our empirical strategy. Section 5 discusses our results, and section 6 concludes.

[1]See for example, among others, Gusev et al. (1998), Nugent et al. (2000), Dubrova et al. (2002), Apsalikov et al. (2013) Grosche et al. (2015), and Yan (2019)

2 Background

Between August 1949 and October 1989 the Soviet Union conducted 456 nuclear tests, a combination of around 116 atmospheric and 340 underground (Table A1), in the Semipalatinsk test site located in the north-east region of Kazakhstan (Figure A1). With 340 test explosions conducted underground and with more than 1,5 million people repeatedly exposed to ionizing radiation (Yan, 2019), this is one of the greatest tragedies not only in history of Kazakhstan but also in the world. The frequency of the tests was such that most of the population living in the Semipalatinsk test site and the nearby areas, have been exposed to up to 30 events in just one year of their life (Figure 1).

Figure 1: Total number of events per year, atmospheric and underground

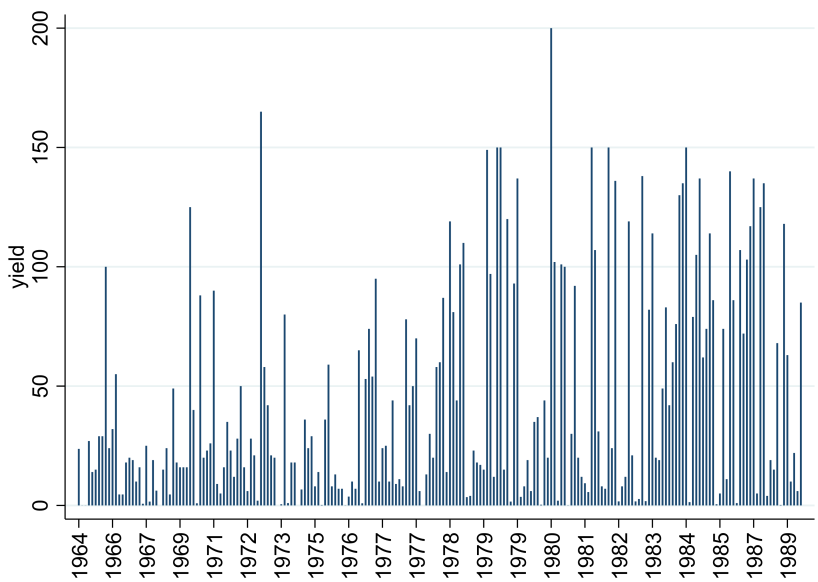


Source: Authors' calculation based on Mikhailov (1996).

The test site covered an area of 18,500 km^2, or 7,143 square-miles (Grosche et al., 2015). For comparison, it is more than seven times larger than the officially designated exclusion zone around the site of the Chernobyl nuclear reactor disaster (Bondarkov et al., 2011).

Furthermore, it is estimated that the total power of nuclear charges tested on the surface before 1963 was 2,500 times higher than the power of the atomic bomb dropped on Hiroshima (Slaus, 2023). Population living in villages on the outskirts of the site were estimated to absorb a cumulative effective dose of radiation between 20 to 2,000 millisieverts - mSv - (EClinicalMedicine, 2019), which is 7 to 740 times more than 2.7 mSv dose of radiation an average person exposed to in a year (UKGov, 2011). Figure 2 plots the yield for each underground explosions in every year, documenting high variation and intensity between 1964 to 1989. Summary statistics of atmospheric explosions are reported in Table A2.

Figure 2: Yield for underground test explosions.



Source: Authors' calculation based on Mikhailov (1996).

3 Data

Administrative divisions and geographical unit Kazakhstan is divided into oblasts, which are administrative regions similar to provinces. Nuclear tests were conducted at specific sites within the larger Semipalatinsk Test Site. Although the precise locations of these tests are well documented, the available datasets for empirical analysis are only disaggregated at the oblast level. Consequently, we cannot analyze the data at a more granular level than the oblast. However, this limitation is not a significant drawback for our analysis, as the radioactive fallout from the tests dispersed over extensive areas. Studies indicate that radiation exposure reached distances of 37 to 260 kilometers from the test site, with some contamination extending up to 300 kilometers, affecting regions like Altai and Ust-Kamenogorsk (Gordeev et al., 2002; Grosche, 2002).

Additionally, evidence shows that nuclear tests also contaminated groundwater and stream water in the Sarzhal area within the test site, influenced by the region's topography and weather conditions (Vintro et al., 2009). This widespread contamination supports our decision to use the oblast as the primary geographical unit for analysis.

Nuclear Tests Data Nuclear tests data are mainly based on the *Ministry of the Russian Federation for Atomic Energy*, and *Ministry of Defense of the Russian Federation* (Mikhailov, 1996). Data contain detailed information on the timing (day, month, year), the exact site (e.g. Semey Test site; Balapan, Delegen ground zero or Sary-Uzen), the latitude, the longitude, the type (if underground or atmospheric), the purpose (if for nuclear weapons related reasonsor other reasons), the yield, the hob for atmospheric explosions. The date of each test allows us to align it with the respondent's exposure period—such as in utero, infancy, or childhood, which is defined in our analysis as ages 0–5.

We do not have information on the actual radiation dose a person's body has absorbed, as actual exposure at the individual level is nearly impossible to measure (Elsner and Wozny, 2023). Given we have information on the yield and hob of explosions, we focus instead on exposure to nuclear explosions by using the frequency of explosive events that an individual encountered as the measure of exposure.

In our analysis we do control for yield in kiloton for underground explosions and height of burst for atmospheric ones. Such measures can be considered as a proxy for the strength of radiation exposure. Yield of the explosion represents the total energy released by the nuclear blast, offering additional context for the scale of radiation dispersion.

Tests were categorized as either atmospheric (above-ground) or underground. Atmospheric tests, conducted before 1962, generated the most widespread radioactive fallout, and most of the radiation exposure to the population (Gordeev et al., 2002; Grosche, 2002), while underground tests had more localized effects (Figure A2 presents cumulative yield per year of underground exposions). To assess the differential health impacts of atmospheric versus underground tests, we introduce the variable Older Cohort, which takes a value of 1 if an individual was born between 1945 (just before when testing began) and 1962 (when atmospheric tests ceased), and 0 otherwise. We then interact this variable with our measure of treatment, introduced below.

Kazakhstan Demographic and Health Survey (KDHS) The Kazakhstan Demographic and Health Survey (KDHS) was conducted by the National Institute of Nutrition in Kazakhstan as part of the worldwide Demographic and Health Surveys (DHS) program, and is a nationally representative survey, collecting information on health, fertility, education, employment, and socioeconomic status at the community, household, and individual levels. For our analysis, we use the 1995 KDHS, although KDHS was also conducted in 1999. However, due to changes in regional administration, the 1999 KDHS does not longer contain information at the same oblast region as 1995, but only at six regional aggregations that would not make the analysis comparable between 1995 and 1999. Moreover the main variables of interest for our study are not available in the 1999 survey. Hence, the 1995

Table 1: Summary Statistics of the Outcome Variables by Region

	All	Semey	Rest of Kazakhstan
Chronic disease	0.299	0.364	0.292
	(0.458)	(0.482)	(0.455)
	N=3,551	N=352	N=3,199
Haemoglobin	11.736	11.865	11.721
	(1.669)	(1.548)	(1.682)
	N=3,442	N=349	N=3,093
Subjective health	3.3549	3.169	3.375
	(0.805)	(0.812)	(0.802)
	N=3,412	N=337	N=3,075
Life satisfaction	3.448	3.445	3.450
	(0.990)	(0.878)	(1.002)
	N=3,430	N=337	N=3,093

Notes: The data source for chronic disease and haemoglobin levels is the 1995 KDHS surveys. Chronic disease is a dummy variable that equals 1 if an individual has chronic disease, 0 otherwise. Haemoglobin (in units g/dl) was measured by taking capillary blood from the fingers. Subjective health and life satisfaction are for East Kazakhstan as Semipalatinsk region was merged with it after 1997 year. Subjective health ranges between 1 (very bad) to 5 (very good). Life satisfaction is ranked on a scale of 1 (strongly disagree) to 4 (strongly agree). Source of data is the LiTS.

KDHS is our main dataset for the analysis. This also allows us to focus on older cohort, who have been exposed to the early and worse radiation.

In 1995, Kazakhstan was divided into 19 administrative regions (oblasts), with Semipalatinsk oblast being a separate region, and its regional centre located in Semipalatinsk city. The Semipalatinsk test site takes its name from the region in which it is located. The region is the unit of our analysis, as we can only identify respondents' residences at the regional level.

Data from KDHS are based on ever-married women aged 18–49 who were interviewed in 1995. This sample includes women born from 1946 onward allowing us to identify individuals who may have been exposed to radiation in utero or during childhood (5 years) due to nuclear testing in Kazakhstan. While comparable data on men is not available in the KDHS, focusing on women is particularly pertinent, as maternal transmission of health conditions to subsequent generations is well-documented (Currie and Moretti, 2007; Akbulut-Yuksel and Kugler, 2016; Almond and Currie, 2011; Almond et al., 2018).

Our main health outcomes from KDHS are a dummy indicator for chronic disease and hemoglobin level in blood. Chronic diseases and hemoglobin levels are highly relevant variables for analyzing the health effects of nuclear radiation because they provide measurable indicators of the body's physiological response to radiation exposure.

Chronic diseases are key indicators since radiation increases the risk of developing long-term health conditions, including cancer, cardiovascular diseases, and respiratory issues. By examining the prevalence of chronic diseases in exposed populations, researchers can track the delayed and cumulative health impacts that may not manifest immediately but develop over years or even decades.

Hemoglobin levels are also crucial because radiation exposure can affect bone marrow, where red blood cells are produced. Low hemoglobin levels, or anemia, can signal damage to the body's ability to produce healthy blood cells, a common consequence of radiation exposure. Monitoring hemoglobin helps assess long-term effects on the circulatory and immune systems, both of which are highly sensitive to radiation. Together, these variables provide insight into both the immediate and long-term health consequences of radiation exposure, making them essential for a comprehensive analysis (Puchala et al., 2002; Vieira et al., 2020).

Life in Transition Survey (LiTS) To analyse subjective health and well-being we draw on the Life in Transition Survey (LiTS) I, II and III, a nationally representative household-level survey conducted by the European Bank for Reconstruction and Development in collaboration with the World Bank, that collects information on the socioeconomic status of respondents and on their attitudes and perceptions concerning a variety of economic, political and social topics. LiTS I, II and III were carried out in 2006, 2010 and 2016 respectively. Although the sample size in each year is relatively small (approximately 1,000 observations), the pooled final sample equals to 3,263 observations that is sufficient to detect relevant effects. Similar to the KDHS, the LiTS only provides regional or oblast-level location data. In contrast to the KDHS dataset, the LiTS dataset does not provide specific information on the former Semipalatinsk oblast, as this oblast was dissolved in 1997 and incorporated into the East Kazakhstan oblast. Therefore, in analyses using LiTS data, we classify individuals residing in the East Kazakhstan region as treated individuals. For consistency with the KDHS analysis, we refer to this region as Semey.

The main outcomes of interest from the LiTS data are subjective health and life satisfaction. Subjective health is based on the question: "*How would you assess your health?*" ranging from 1 (very good) to 5 (very bad). People living in East Kazakhstan oblast (including Semipalatinsk oblast residents), report on average, a worse assessment of their health than residents of other oblasts (Table 1). To ease of interpretation in empirical analysis the values have been reversed and standardized between 0 (mean) and 1 (standard deviation), so lower values indicate now worse subjective health, while higher ones indicate better subjective health.

By the time of the LiTS surveys (2006, 2010 and 2016), residents of these regions were likely aware of the nuclear contamination and may have directly or indirectly experienced its health effects. This awareness may influence their life satisfaction, which is measured using the statement: *"All things considered, I am satisfied with my life now,"* rated on a scale of 1 to 5, from "strongly disagre" to "strongly agree." Similarly to the subjective health, for interpretation purposes, we standardize this variable with a mean of 0 and a standard deviation of 1. Negative values indicate lower life satisfaction, while positive values indicate higher satisfaction. We focus on older individuals (aged 37 or older at the time of the interview), as they are more likely to have been exposed to stronger atmospheric nuclear explosions carried between 1946 and 1962, and to have greater awareness of the long-term health consequences.

Measuring exposure to nuclear tests In our analysis, our baseline treatment variable is *Semey*, a dummy variable that equals one if an individual is residing the Semipalatinsk oblast (or East Kazakhstan oblast) at the time of the interview, 0 otherwise. As mentioned before, we do not have information on birth place. Given the low mobility in Kazakhstan, we believe that using the location of residence at the time of the survey is a good proxy for when they were born. While this is common in similar existing studies (see for example, Danzer and Danzer (2016)), later on we explain why this limitation is unlikely to affect our results. Morever, we also control for the length of residence in the oblast, being then able to identify those who have always lived in the same area.

We also use a second treatment variable, *High Explosion Semey*, to measure exposure to explosions at a high intensity. Specifically, among KDHS women who were living in the Semipalatinsk oblast, we consider those who were exposed to more than 20 explosions a year at any time from before they were born (in utero) and up to 5 years of age, as treated. Women who were born in the same years but were not living in the Semiplalatinski region form the comparison group. Years with high intensity of explosions, defined as having more than 20 explosions per year, include 1961 to 1962; 1977 to 1981, and 1987.[2] Such analysis is particularly relevant for physical outcomes, as the consequences for women are more likely to be transmitted to later generations.

Additionally, we consider an interaction effect between Semey and the older cohort iden-

[2]That is, only individuals who *would have been* exposed to more than 20 explosions per year at any time from in utero to 5 years old are in the regression, with those not in Semey are in the control. This way, we compare similar birth cohorts. This explains why the number of observations in regression analysis reported in Table 2 from 3442 observations in columns 1 and 4, to 1813 observations in columns 2 and 5.

tified as respondents, in both KDHS and LiTS, born between 1945 and 1962, the time characterized by atmospheric exposure, known to have produced the most widespread radioactive fallout.

4 Empirical strategy

Identification of the causal effect relies on two sources of plausibly exogenous variation: month-place of tests and month-place of individuals' living region. This allows us to provide a causal interpretation of the estimated impact of repeated exposure to nuclear weapon tests on later health and subjective wellbeing. The identification assumption is that in the absence of the nuclear tests, the physical health of individuals in Semipalatinsk region would have been the same or very similar to ones of residents of other regions.

We estimate the following regression model:

$$H_{it} = \beta_0 + \beta_1 E_{it} + \beta_2 X_{it} + \delta_r + \theta_e + \epsilon_{it} \tag{1}$$

where H_{it} represents the outcome variable for individual i in year t (hemoglobin expressed in grams per deciliter (g/dl); a dummy variable for chronic disease, or a value of subjective health or life satisfaction); E_{it} represents the exposure coefficient for each of the measure of exposure adopted; X_{it} indicates individual controls, that can differ depending on the data and on the dependent variable of interest.

For analysis with KDHS dataset, controls including dummy variable if living in rural area; age, age squared, years of education, family size, childhood place of residence (city, town or countryside), year of interview, years lived in current place of residence, a dummy indicating if currently working, and a categorical variable for type of employment (paid, self-employed, unpaid, in all cases if at home or away). For analysis of LiTS data, controls include age, age squared, a dummy for minority ethnicity; a dummy for living in rural area; a dummy for married; a dummy indicating if the respondent has been working in the past 12 months; religion (atheistic/agnostic/none, christian, muslim, other); education (lower education, secondary, post-secondary, tertiary or above); year of interview (2006, 2010, 2016), a dummy for stayers.

We also repeat the analysis, by splitting the sample into "stayers" and "movers" for life and health satisfaction measures. "Stayers" refers to those who report having always lived in the same area, and are likely to capture to be those who were born in an oblast and never moved, while "Movers" refers to those who have ever migrated from any region. For both datasets δ_r refers to the region fixed effect, θ_e captures the yield and height of explosion events, and ϵ_{it} is an error term. For hemoglobin estimates, we also include a dummy variable for current pregnancy status. Standard errors are clustered at the oblast level. Weights are used throughout.

5 Results

5.1 Exposure to tests and health

Table 2 shows that exposure to explosions significantly contributes to adverse health outcomes, as measured by incidence of chronic disease and anemia. Specifically, individuals exposed to explosions have a 6.74% higher probability of experiencing chronic disease compared to unexposed individuals (Table 2, Column 1). High-intensity exposure is associated with an even larger estimated effect, indicating that such exposure corresponds to a 9.04% increase in the likelihood of chronic disease, suggesting that higher exposure intensity raises the risk of chronic disease by nearly 2% (Column 2). The older cohort, born between 1945 and 1962, has a higher probability of chronic disease than the younger generation in the Se-

Table 2: Nuclear Explosions and Health

Dep. var.	Chronic			Anemia		
	(1)	(2)	(3)	(4)	(5)	(6)
Semey	0.0674***		0.0409***	0.0492***		0.00133
	(0.00764)		0.0124)	(0.00737)		(0.0164)
High explosion Semey		0.0904***			0.150***	
		(0.0184)			(0.0132)	
Semey × Old Cohort			0.0535**			0.0963***
			(0.0228)			(0.0262)
Old Cohort			-0.0319			-0.120**
			(0.0545)			(0.0498)
Constant	0.261**	-0.0180	0.276**	0.281	-0.115	0.339*
	(0.115)	(0.175)	(0.116)	(0.184)	(0.248)	(0.186)
Controls	Yes	Yes	Yes	Yes	Yes	Yes
Birth month fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Oblast dummies	Yes	Yes	Yes	Yes	Yes	Yes
Mean of dep. var.	0.306	0.255	0.306	0.501	0.503	0.501
Observations	3,551	1,863	3,551	3,442	1,813	3,442
R-squared	0.126	0.110	0.126	0.063	0.081	0.065

Notes: The dependent variable is chronic disease (0/1) in columns 1 to 3 and whether the respondent has anemia, based on measured levels of haemoglobin in the blood being less than 11.9 g/dl, in columns 4 to 6. Additional controls not reported include age, years of schooling, mean hob and yield of explosions experienced from in utero up to 5 years of age, family size, a dummy variable indicating rural area of residence, whether the respondent is working, whether she is pregnant at the time of the survey, childhood place of residence (city, town, countryside), years lived in place of residence. Standard errors are clustered at the oblast level. *** p<0.01, ** p<0.05, * p<0.1.

mey region, suggesting that cumulative exposure effects are critical, with the type of exposure also likely playing a role—atmospheric tests, more devastating than underground tests, were predominant during this period. Age alone does not appear to significantly contribute to chronic disease likelihood (Column 3).

For anemia, the results are more mixed. As with chronic disease, exposure to explosions in-creases the likelihood of anemia by 5%, and by up to 15% under high exposure intensity (Columns 4 and 5). However, these results are primarily driven by older individuals. For comparison, our estimates are significantly greater than those of the study, which examined the long-term effects of radiation on hemoglobin levels over a 40-year period, from 1958 to 1998, in Japan's atomic bomb survivors. The study found that at 40 years of age, survivors exhibited a reduction in hemoglobin levels of 0.67%, while at 80 years of age, the same group showed a reduction of 1.8% (Wong et al., 2005). Their results align with ours, suggesting that the impact of radiation exposure on hemoglobin levels becomes more pronounced with age. While the younger cohort in Semey may also experience elevated anemia risk, the statistical power of the analysis is insufficient to establish this conclusively. Age alone, without explosion exposure, appears to have a protective effect against anemia.

Overall, the findings indicate that exposure to nuclear explosions significantly raises the risk of chronic disease and anemia, with higher intensity exposure linked to an even greater likelihood of adverse health outcomes. The older cohort, particularly those exposed to atmospheric tests in the Semey region, faces the highest risk, highlighting the long-term health impact of cumulative, high-intensity radiation exposure.

A potential confounding factor to our analysis is residential sorting, which could be significant if individuals exposed to nuclear tests in the Semey area chose to move away, creating selection into treatment (Elsner and Wozny, 2023). However, two main reasons suggest that this is unlikely to impact our estimates. First, while we control for the duration of residence in the regressions, information about nuclear testing was withheld from the general public (Mussabalinova, 2023) (Stawkowski, 2016). Residents only became aware of the tests and their harmful effects shortly before the Soviet Union's collapse, when this information was released under Mikhail Gorbachev's glasnost policies Stawkowski (2016). This lack of awareness about nuclear testing as a barrier to avoidance behavior has been documented in previous research, such as the case of nuclear testing in Norway, where estimates were considered unlikely to be influenced by selective migration (Black et al., 2019). This situation parallels that of the Semipalatinsk area in Kazakhstan. Second, residential mobility within and outside the Soviet Union was tightly restricted (Danzer and Danzer, 2016; Lehman and Wadsworth, 2011). The Soviet internal passport system severely limited individual mobility and market choice, further reducing the likelihood of selective relocation Gregory and Kohlhase (1988).

5.2 Exposure to explosions and subjective health

In this section, we examine how living in areas exposed to nuclear explosions and gender affect individuals' perceived health (Table 3), using data from the LiTS. The regression results indicate that individuals residing in East Kazakhstan oblast (which includes the former Semipalatinsk oblast) at the time of the survey perceived their health to be worse than residents of other regions by approximately 14 percentage points (%). Female respondents generally reported worse health perceptions than males, with an average decrease of 11.2 percentage points (Column 1). Health dissatisfaction among residents of the Semipalatinsk region is primarily driven by the older cohort, born between 1945 and 1962 and exposed to the atmospheric explosions, whose health satisfaction is approximately 27.3 percentage points lower than that of the younger cohort in the same region. Furthermore, younger individuals in Semipalatinsk perceive their health as worse than their peers in other regions by 6.8% (Column 2).

The LiTS dataset provides information on respondents' current place of residence and whether they have always lived in that region but does not specify respondents' birthplaces. While internal migration was low during the Soviet Union era, it has increased significantly in more recent years. To address the possibility that some people have moved to the region without direct exposure to early nuclear explosions, we conduct an analysis comparing 'Stayers' and 'Movers'. Results indicate that the old cohort in the Semipalatinsk region, now part of East Kazakhstan oblast, report greater health dissatisfaction than older individuals

Table 3: Exposure to Explosions and Subjective Health

Sample	All	All	Stayers	Movers
	(1)	(2)	(3)	(4)
Semey	-0.140***	-0.068***	0.103	-0.189***
	(0.015)	(0.021)	(0.068)	(0.043)
Semey X Old Cohort		-0.273***	-0.185**	-0.151*
		(0.047)	(0.067)	(0.079)
Old Cohort		0.075**	0.067	0.031
		(0.030)	(0.071)	(0.055)
Female	-0.112***	-0.108***	-0.121**	-0.103
	(0.030)	(0.030)	(0.045)	(0.092)
Constant	0.845***	0.889***	0.797**	0.909**
	(0.257)	(0.259)	(0.287)	(0.304)
Oblast dummies	Yes	Yes	Yes	Yes
N. Atmospheric and underground event	Yes	Yes	Yes	Yes
Mean of subjective health	3.355	3.355	3.472	3.368
Stan. Dev. of subjective health	0.805	0.805	0.781	0.781
Observations	3,253	3,253	1,320	949
R-squared	0.244	0.246	0.257	0.258

Notes: Based on LiTS I, II and III. Columns (3) and (4) are based on LiTS II and III. Dependent variable is subjective health ranging from 1 (very bad) to 5 (very good), standardized between 0 and 1. Additional controls not reported are: age dummies; a dummy for minority ethnicity; a dummy for living in rural area; a dummy for married; a dummy if working; religion (atheistic/agnostic/none, Christian, Muslim, other); education (lower education, secondary, post-secondary, tertiary or above); year of interview (2006, 2010, 2016). Stayers refers to those who report having always lived in the same area. Robust standard error clustered at oblast level. $***p < 0.001, **p < 0.05 ***p < 0.1$.

in non-exposed regions, regardless of mobility status. However, health perceptions among the younger cohort vary based on mobility: young movers to the exposed region report worse health perceptions than young non-movers in other regions, by 18.9%, whereas young stayers in the region do not report significantly worse health perceptions compared to peers in other regions (Columns 3 and 4).

Table 4: Exposure to Explosions and Life Satisfaction

Sample	All	All	Stayers	Movers
	(1)	(2)	(3)	(4)
Semey	-0.051***	-0.005	0.388***	-0.241***
	(0.010)	(0.018)	(0.038)	(0.055)
Semey X Old Cohort		-0.183***	-0.740***	0.469***
		(0.045)	(0.044)	(0.073)
Old Cohort		0.131**	0.118**	-0.060
		(0.050)	(0.050)	(0.138)
Female	-0.045	-0.040	0.004	0.131
	(0.031)	(0.031)	(0.049)	(0.099)
Constant	0.586**	0.715***	0.273	-0.058
	(0.204)	(0.205)	(0.292)	(0.263)
Oblast dummies	Yes	Yes	Yes	Yes
N. Atmospheric and underground event	Yes	Yes	Yes	Yes
Mean of life satisfaction	3.448	3.448	3.497	3.450
Stan. Dev. of life satisfaction	0.990	0.990	0.972	0.977
Observations	3,262	3,262	1,327	951
R-squared	0.106	0.108	0.176	0.238

Notes: Based on LiTS I, II and III. Columns (3) and (4) are based on LiTS II and III only. Dependent variable is life satisfaction ranging from 1 (strongly disagree) to 5 (strongly agree), standardized between 0 (mean) and 1 (standard deviation). Additional controls not reported are: age; age squared; a dummy for minority ethnicity; a dummy for living in rural area; a dummy for married; a dummy if working; religion (atheistic/agnostic/none, christian, Muslim, other); education (lower education, secondary, post-secondary, tertiary or above); Stayers refers to those who report having always lived in the same area. Robust standard error clustered at oblast level. $***p < 0.001, **p < 0.05, ***p < 0.1$.

5.3 Exposure to explosions and Life Satisfaction

Differences in life satisfaction among Semipalatinsk residents also vary by mobility status. The "stayers" in Semipalatinsk report greater life satisfaction, by 38.8 percentage points, whereas older stayers report considerably lower life satisfaction, by 74 percentage points. For "movers" to the region, the pattern is reversed: young movers report 24.1 percentage points lower life satisfaction, while older movers report an increase in satisfaction by 46.9 percentage points. Gender does not have a significant effect on life satisfaction scores. The findings suggest that life satisfaction in East Kazakhstan, especially among residents of

Semey, is notably impacted by cohort and mobility status, with older stayers reporting the highest dissatisfaction levels. Young stayers, however, report increased satisfaction, highlighting complex interactions between exposure, mobility, and life satisfaction.

In sum, the results in Tables 3 and 4 show that for Semey residents, particularly older stayers, nuclear test exposure is associated with significantly lower health and life satisfaction, highlighting a persistent impact on those continuously exposed (Columns 1 and 2). Subjective health also confirms the results reported on objective health from the KDHS. In contrast, younger stayers do not show a significant decline in health or life satisfaction, suggesting generational resilience or adaptation over time. These findings underscore the lasting effects of nuclear tests on older long-term residents' well-being in Semey. Women across all regions report consistently lower health satisfaction than men, suggesting that gender-based factors, such as differential health perceptions or access to health resources, may impact women's health satisfaction more broadly. However, this does not necessarily carry over to life satisfaction, indicating that women might derive life satisfaction from aspects beyond health alone, or that life satisfaction may be less sensitive to health status across genders. Statistical power limitations could also mean subtle effects on life satisfaction may not be fully captured.

6 Conclusion

This study highlights the profound and lasting impact of nuclear explosions on both the objective and subjective health and well-being of populations in the Semey region. Exposure to radiation is significantly linked to higher rates of chronic disease and anemia, particularly among older cohorts who experienced atmospheric testing in utero or during their first five years of life. Additionally, the findings reveal that longer and earlier exposure to nuclear radiation is associated with lower life satisfaction.

These results underscore the critical need for public health measures to mitigate the long-term consequences of radiation exposure. Policies must prioritize protecting children, especially in utero and during early childhood, as the effects of such exposure are often irreversible. Furthermore, the study highlights the necessity of ongoing health and social support programs for affected populations to address both the physical and psychological legacies of nuclear testing.

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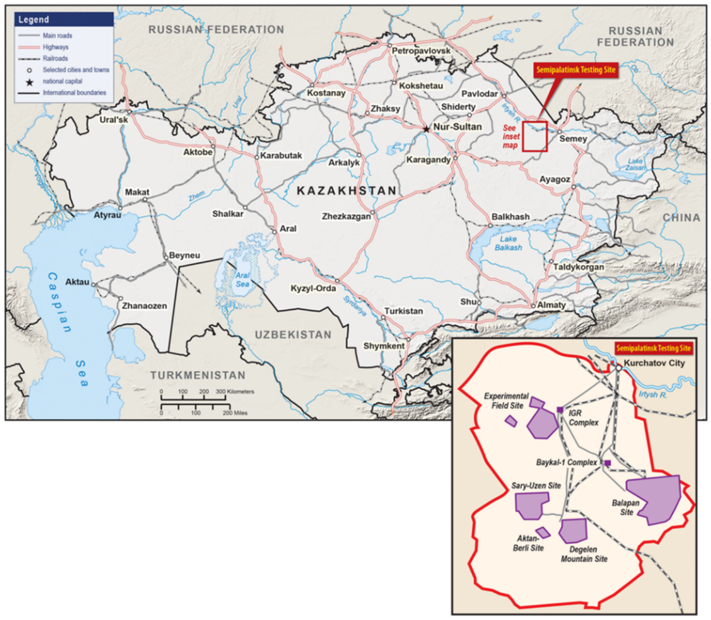
Appendix

Figure A1: Kazakhstan and Semipalatinsk Nuclear Test



Source: Kassenova (2022)

Table A1: Summary Statistics of Explosions, 1949-1989

	Atmospheric	**Underground**	**Total**
Total Number of Events	100	340	440
Percentage (%)	22.7	77.3	100
Year Range	1949-1962	1964-1989	-
Latitude (Mean)	50.1	49.9	-
Longitude (Mean)	77.9	78.4	-
Ground Zero Altitude (Tunnel Underground)	-	670.6	-
Height of Blast (Average)	513	-	-
Average Number of Events per Year	10	14	-
Minimum Number of Events per Year	1	2	-
Maximum Number of Events per Year	30	29	-

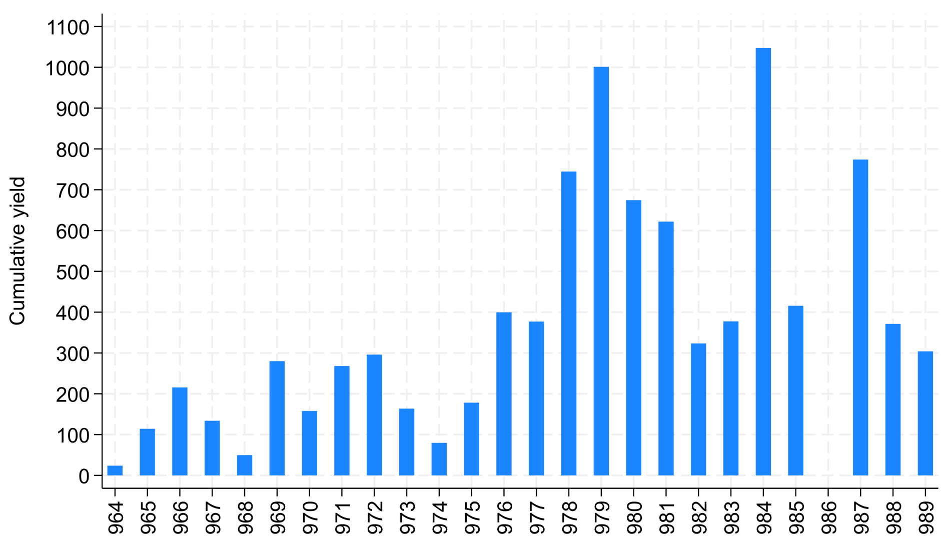
Source: Authors' calculation based on Mikhailov (1996)

Table A2: Yield of Atmospheric Weapon Explosions

Year	N. Events	Yield		Height of Burst	
		Mean	Max	Mean	Max
1949	1	22	22	30	30
1951	2	40	42	205	380
1953	5	88	400	265	600
1954	9	9	62	148	410
1955	5	373	1600	512	1550
1956	8	247	900	810	2000
1957	10	169	680	1328	2000
1958	7	12	35	829	1415
1961	23	6	21	506	725
1962	30	6	23	503	740
Total	**100**	**97**	**379**	**513**	**985**

Source: Authors' calculation based on Mikhailov (1996)

Figure A2: Cumulative yield per year of underground explosions



Source: Authors' calculation based on Mikhailov (1996).