RESEARCH ARTICLE

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Thyroid Cancer and Precancerous Morbidity After Nuclear Fallout: Long-Term Cohort Study Near the Semipalatinsk Test Site

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Abstract

Background: Populations living near the Semipalatinsk Nuclear Test Site (SNTS) in Kazakhstan were chronically exposed to low-to-moderate doses of ionizing radiation due to atmospheric nuclear testing (1949-1962). While the effects of acute exposures are well documented, data on long-term endocrine outcomes in chronically exposed adults remain limited. **Objective:** To evaluate thyroid and metabolic morbidity and its association with reconstructed radiation dose in a long-term adult cohort exposed to fallout. **Methods:** This cohort study included 3,240 individuals who underwent thyroid ultrasound screening between 1998 and 2002. Thyroid doses were reconstructed individually using a fallout-specific dosimetric model based on age, diet, and geographic location across 125 nuclear tests. Endocrine outcomes were assessed through ICD-10 diagnoses and follow-up surveys in 2023–2024. Associations between dose and endocrine morbidity were analyzed using logistic regression, adjusted for sex, age at exposure, smoking, obesity, parity, and hormone therapy. **Results:** By 2024, 1,099 individuals (33.9%) were alive. Among them, 63% reported thyroid disease, 33% had received hormone therapy, and 2% had undergone surgery. Verified endocrine diagnoses were identified in 712 individuals (21.9%), including non-toxic diffuse goiter (28.1%), multinodular goiter (19.5%), and single nodular goiter (7.9%). Thyroid dose was positively associated with endocrine morbidity (OR = 1.42; 95% CI: 1.22–1.65; $p < 0.001$). Female sex, early exposure, obesity, and smoking were also significant predictors. **Conclusions:** Decades after fallout exposure, thyroid and metabolic disorders remain prevalent in affected populations. The findings support continued endocrine surveillance and provide robust evidence of a dose-dependent endocrine risk in adults exposed to environmental radiation.

Keywords: ionizing radiation- thyroid disorders- chronic exposure- dose–response- retrospective cohort

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Introduction

Thyroid cancer incidence has shown a global increase over the past several decades, raising concerns about both environmental and individual risk factors that remain insufficiently understood [1, 2]. The thyroid gland, due to its central role in metabolism and high radiosensitivity, is particularly susceptible to the effects of ionising radiation [3, 4]. Populations residing near the Semipalatinsk Nuclear Test Site (SNTS) in Kazakhstan were chronically exposed to both external and internal radiation due to atmospheric nuclear weapons testing conducted between 1949 and 1962 [5, 6].

Major exposure pathways included prolonged background gamma radiation and ingestion or inhalation of radioactive isotopes, particularly iodine-131, through contaminated food and water [7, 8]. Understanding the synergistic role of ionising radiation and non-radiation risk factors such as genetic predisposition, lifestyle, and thyroid comorbidities is essential for clarifying the mechanisms of radiation-induced thyroid carcinogenesis [9].

While the Chernobyl accident has provided robust evidence regarding the risk of thyroid cancer following childhood and adolescent exposure to radioiodine [10, 11], there remains a significant lack of data on long-term thyroid cancer risk in adults subjected to chronic low-dose exposure, particularly from non-medical sources [12, 13]. Furthermore, prospective studies documenting the natural progression of thyroid nodules and their transformation into malignancies remain rare, especially in radiation-exposed populations [5, 14].

Initial cross-sectional surveys conducted in the late 1990s among residents of settlements near the SNTS

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reported a high prevalence of thyroid nodules and found significant associations between cumulative thyroid radiation dose and the occurrence of nodular disease [15, 16]. However, follow-up studies have been limited, leaving the long-term dynamics of thyroid pathology in this population largely uncharacterised.

The Semipalatinsk cohort represents a uniquely informative population because exposure resulted from repeated atmospheric nuclear tests over a prolonged period (1949-1962), leading to chronic low-to-moderate cumulative thyroid doses rather than the acute high-dose exposures observed in events such as Chernobyl or the Marshall Islands. Unlike other well-studied irradiated populations, this cohort comprises adults exposed throughout different life stages and allows long-term assessment of both structural and functional thyroid disorders. These characteristics make the Semipalatinsk cohort one of the few large-scale, chronically exposed populations suitable for evaluating dose-response relationships across adulthood.

The objective of the present study is to provide a comprehensive long-term evaluation of thyroid and endocrine morbidity in a population chronically exposed to nuclear fallout near the Semipalatinsk Test Site. By tracing the evolution of thyroid nodules and integrating individual-level data on radiation dose, endocrine diagnoses, and lifestyle-related factors, this study aims to elucidate both radiation-dependent and independent risk pathways. This research constitutes one of the most extensive thyroid health surveillance efforts conducted in a fallout-exposed adult population and is expected to refine dose-response models, identify vulnerable subgroups, and contribute to global evidence on radiation-related thyroid pathology [17].

Materials and Methods

Study Design and Population

This cohort study was conducted in the framework of a scientific startup project supported by the NCJSC Semey Medical University (2023–2025), aimed at investigating long-term thyroid health outcomes in individuals exposed to ionizing radiation from the Semipalatinsk Nuclear Test Site (SNTS). The study population consisted of 3,240 individuals who underwent thyroid ultrasound screening between 1998 and 2002 and resided in radiation-contaminated villages in the Abai, Beskaragay, Borodulikha, and Kurchum districts of eastern Kazakhstan.

Cohort Formation and Data Sources

To establish the study cohort, an integrated electronic database ("Thyroid Cohort") was developed using multiple sources, including: historical thyroid ultrasound records (1998–2002), the State Scientific Automated Medical Registry, the Kazakhstan Medical Information System, vital records from the Civil Registry Offices, and updated follow-up medical and demographic information.

Each cohort member was assigned a unique encrypted identifier to ensure confidentiality and facilitate data linkage across systems. The database contains comprehensive demographic details, residential history, occupational status, vital status, and-where applicable-cause of death, thereby allowing reconstruction of individualized radiation exposure trajectories.

Thyroid Ultrasound Data

A separate database, "Thyroid Ultrasound Results," was established to assess the morphological evolution of thyroid nodules. It includes information from both initial (1998-2002) and current ultrasound examinations of surviving cohort members (n = 1,099). Recorded parameters include thyroid volume, echogenicity, structural heterogeneity, nodule number, location, and size. All new examinations were conducted by trained sonographers using standardized protocols.

Questionnaire Survey

Between 2023 and 2024, all living members of the cohort were invited to participate in a structured questionnaire survey conducted either at the Institute of Radiation Medicine and Ecology or during field visits. The questionnaire collected information on personal and family history of thyroid disease, use of thyroid hormone therapy and history of thyroid surgery, smoking and alcohol consumption, reproductive history (for women), and residential history to support individualized radiation dose reconstruction. Written informed consent was obtained from all participants.

Endocrine Morbidity and Medical History Extraction

Endocrine morbidity data were extracted from six official medical sources: the State Scientific Automated Medical Registry, the Kazakhstan Medical Information System, the oncology and endocrinology departments of the Institute of Radiation Medicine and Ecology, hospital discharge records, and the regional radiation-exposure expert registry.

Diagnoses were coded according to the ICD-10 classification. A dedicated database ("Endocrine Morbidity") was developed to enable assessment of disease prevalence and temporal trends within the study cohort.

Radiation Dose Reconstruction

Individual thyroid radiation doses (in mGy) were reconstructed using a multi-pathway dosimetric model adapted for fallout scenarios around SNTS. This included:

External exposure from gamma radiation due to nuclear fallout, Internal exposure from ingestion of radioiodines (I131, Te132/I132, I133) via contaminated milk and other dairy products, Breastfeeding (for infants under 1 year) and dietary habits were considered based on ethnographic data.

Doses were calculated for each nuclear test (n = 125) relevant to an individual's age, nationality, and location at the time of exposure. The dosimetric methodology is based on models published in Health Physics (2022) and Radiation and Environmental Biophysics (2011), incorporating region-specific parameters such as livestock grazing practices, milk yield, and radionuclide retention on vegetation.

This reconstruction approach represents one of the most detailed and individualized retrospective dose assessments conducted outside the Chernobyl context. The model integrates data from 125 distinct nuclear tests and is tailored to individual characteristics such as age at exposure, ethnicity-specific dietary patterns, breastfeeding history, and livestock practices. It builds upon previously validated fallout exposure models (e.g., ECOSYS-87 and Health Physics frameworks), and adapts them to local environmental and behavioral conditions. This level of granularity enhances the credibility of dose-response analyses and addresses key limitations present in earlier ecological or regionally averaged studies.

As with all retrospective fallout dosimetry, individual thyroid dose estimates contain inherent uncertainties arising from gaps in historical environmental measurements, variability in dietary recall, and test-specific deposition patterns. Based on previous validation studies of fallout dosimetry models applied in the Semipalatinsk region and other exposed populations, typical uncertainty ranges are within a factor of 2-3 for individual thyroid dose estimates. While detailed individual uncertainty intervals could not be reconstructed for each cohort member due to incomplete historical records, these uncertainties are expected to be non-differential with respect to endocrine outcomes. Therefore, they would likely attenuate the observed dose-response relationship rather than produce spurious associations.

Thyroid dose reconstruction was possible for 2,713 out of 3,240 cohort members (83,7%). For the remaining 527 individuals, essential historical information, such as residential records during the years of test fallout, dietary behavior, or breastfeeding history, was missing or incomplete. Because the fallout dosimetry model requires full individual-level data to link exposure to specific nuclear tests, dose estimation could not be performed for these participants. Missingness was unrelated to medical outcomes and primarily reflected gaps in archival documentation; therefore, systematic bias is unlikely.

Statistical Analysis

Descriptive statistics were used to summarize demographic characteristics, radiation dose distributions, and the prevalence of endocrine diagnoses. Means and standard deviations (SD) were used for normally distributed continuous variables, and medians with interquartile ranges (IQR) for skewed distributions. Categorical variables were compared using chi-square tests, and continuous variables using t-tests or Mann-Whitney U tests, as appropriate.

To assess potential multicollinearity among predictors (e.g., sex, parity, thyroid hormone therapy), variance inflation factors (VIFs) were evaluated for all variables included in the multivariable model. All VIF values were below 2.0, indicating the absence of problematic multicollinearity. Sensitivity analyses excluding parity and hormone therapy produced similar effect estimates, confirming the stability of the model.

To explore the association between radiation and non-radiation risk factors and the presence of endocrine morbidity, binary logistic regression analysis was performed. The dependent variable was the presence of at least one verified ICD-10 endocrine diagnosis. Independent variables included log-transformed thyroid radiation dose (in mGy), sex, age at radiation exposure (<5 years vs. ≥5 years), smoking history, obesity (ICD-10 E66), parity (≥3 pregnancies among females), and thyroid hormone therapy.

All statistical analyses were conducted using SPSS version 26.0 (IBM Corp., Armonk, NY). Statistical significance was defined as $p < 0.05$. The study protocol was approved by the Local Ethics Committee of Semey Medical University (Protocol No. 7, March 16, 2022). Written informed consent was obtained from all participants for study participation and the processing of personal data.

Results

Cohort Verification and Demographic Composition

The initial cohort included 3,240 individuals who underwent thyroid ultrasound examinations between 1998 and 2002 in rural settlements located near the Semipalatinsk Nuclear Test Site. These participants formed the foundation for long-term follow-up and multifactorial risk analysis.

During the current study phase, all baseline records were reverified and updated using national medical and civil registries. As of the most recent update, 33.9% (n = 1,099) of the cohort were alive, 60.1% (n = 1,945) were deceased, 5.9% (n = 192) had relocated and were lost to follow-up, and 0.1% (n = 4) had unknown status. This distribution is visualized in Figure 1.

The high mortality rate reflects the aging profile of the cohort and underscores the importance of sustained longitudinal surveillance in radiation-exposed populations. Among 3,240 participants, 60.1% were deceased and 33.9% were alive as of the latest data verification (2024). The remaining 6% were either lost to follow-up or had unknown status.

Although vital status information was obtained from national civil registries, detailed medical causes of death were not available for most deceased cohort members. The majority of death certificates contained only high-level ICD codes or non-specific entries, which did not allow reliable classification of mortality patterns. Therefore, it was not possible to analyse mortality in relation to endocrine morbidity or reconstructed thyroid radiation dose. Accordingly, survival and mortality outcomes were not included in the dose-response analysis.

Radiation Dose Distribution

Individual thyroid radiation doses were reconstructed for 2,713 of 3,240 cohort members (83.7%) based on age, residential history, dietary behavior, and proximity to fallout zones during atmospheric nuclear weapons testing at the Semipalatinsk Nuclear Test Site. Dose modeling accounted for both external gamma radiation and internal exposure from ingestion of radioiodines through locally produced milk and dairy products.

The reconstructed thyroid doses ranged from <3 mGy to >1,000 mGy. The average (± standard deviation) dose

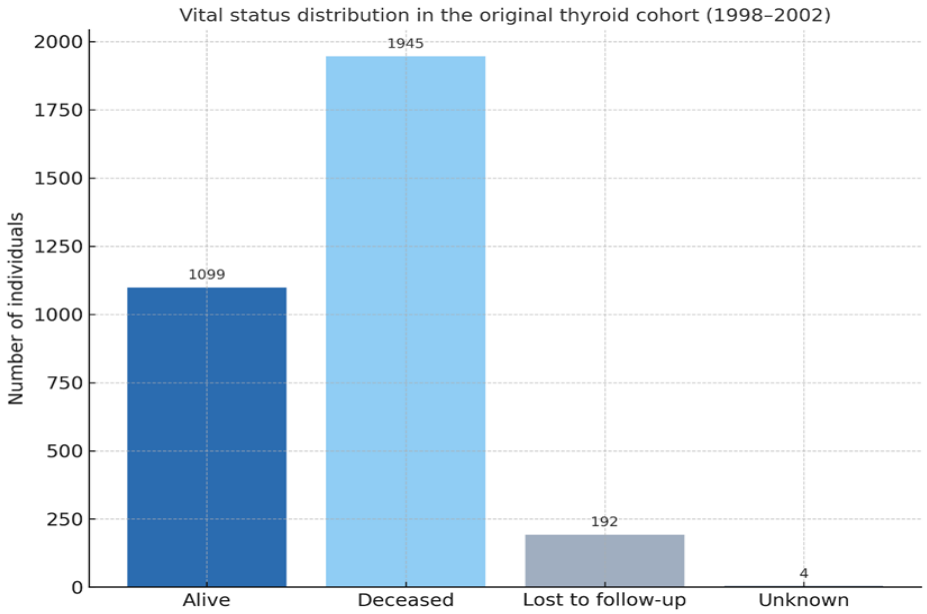

Figure 1. Vital status Distribution of Cohort Members Originally Examined between 1998 and 2002.

across all individuals with non-zero values was 260 ± 355 mGy, with a median dose of 140 mGy. Table 1 provides the distribution of cohort members by dose categories.

Questionnaire-Based Characteristics

To evaluate potential non-radiation-related risk factors for thyroid disease, structured interviews were conducted with 1,099 living cohort members. Overall, 63% of respondents reported a history of thyroid disease, 33% had received thyroid hormone therapy, and 2% had undergone thyroid surgery. Lifestyle habits revealed that 21% were regular smokers, with a marked sex difference (41.2% among men vs. 4.8% among women). Alcohol consumption was also significantly higher in men (68.3%) compared to women (19.4%). Among 790 women who provided reproductive history, the majority had two or more pregnancies, reflecting high fertility rates typical of rural Central Asian populations.

Endocrine Morbidity

To investigate the broader burden of endocrine disease within the exposed cohort, a dedicated database of verified endocrine diagnoses was compiled from six official sources, including national medical registries and institutional clinical records. Diagnoses were coded according to ICD-10 standards. Overall, 712 cohort members (21.9%) were identified as having one or more endocrine disorders.

The most prevalent thyroid conditions included non-toxic goiter variants: E04.0 (non-toxic diffuse goiter, 28.1%), E04.2 (non-toxic multinodular goiter, 19.5%), and E04.1 (non-toxic single nodular goiter, 7.9%). In total, these three categories accounted for over half (55.5%) of all documented endocrine diagnoses. Other notable thyroid conditions included autoimmune thyroiditis (E06.3, 3.1%), hypothyroidism (E03 and its subtypes, 3.1%), and thyrotoxicosis (E05.0, 0.1%). In addition, 12 cases of malignant neoplasm of the thyroid gland (C73, 1.7%) and 7 unspecified cases (C73.9, 1.0%) were recorded.

Beyond thyroid pathology, metabolic conditions such as type 2 diabetes mellitus (E11 and subcodes, 10.1%) and obesity (E66 and subcodes, 4.8%) were also frequently observed, suggesting potential comorbidities requiring further exploration in multivariate models.

A detailed breakdown of endocrine diagnoses is provided in Figure 2, which illustrates the frequency of the most common ICD-10 codes among affected cohort members. The figure presents the most frequently observed endocrine disorders in the study cohort (n = 712 individuals with verified endocrine morbidity). Non-toxic goiters (E04.0, E04.2, E04.1) accounted for over 55% of all diagnoses, followed by type 2 diabetes mellitus (E11), autoimmune thyroiditis (E06.3), and hypothyroidism (E03 group). Malignant thyroid neoplasms (C73 and C73.9) were also identified.

Risk Facto Synthesis and Multivariable Analysis

To identify independent predictors of endocrine morbidity within the exposed cohort, a multivariable

Table 1. Distribution of Reconstructed Thyroid Radiation Doses in the Study Cohort

	Number of Individuals	% of Cohort
Thyroid Dose (mGy)		
< 3	108	4.0%
3–10	207	7.6%
10–30	418	15.4%
30–100	431	15.9%
100–300	1,000	36.9%
300–1000	402	14.8%
> 1000	147	5.4%
Total	2,713	100.0%

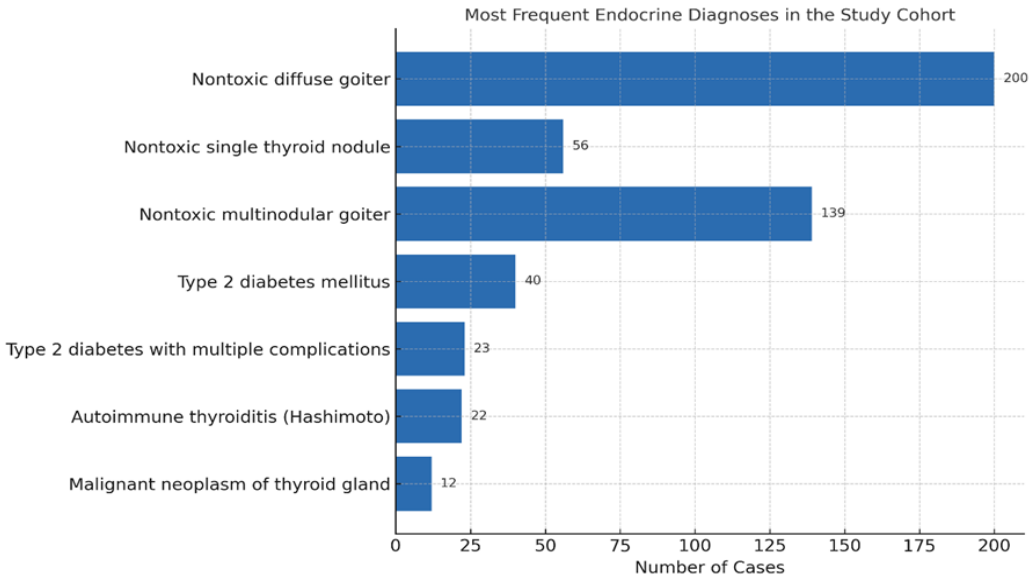

Figure 2. Distribution of Endocrine Diagnoses (ICD-10 codes) among Cohort Members

logistic regression model was constructed. The outcome variable was the presence of one or more verified endocrine disorders, as documented in the ICD-coded diagnostic registry. Predictor variables included demographic characteristics, lifestyle behaviors, reproductive history, and reconstructed thyroid radiation dose (log-transformed for normalization).

The results, summarized in Table 2 and visualized in Figure 3, revealed several significant associations

Radiation dose (log-transformed) was positively associated with endocrine morbidity (OR = 1.42, 95% CI: 1.22–1.65, $p < 0.001$), confirming a dose-dependent risk even decades after exposure.

Female sex was a strong independent predictor (OR = 2.15, 95% CI: 1.78–2.60, $p < 0.0001$), likely reflecting the higher prevalence of thyroid and autoimmune conditions in women.

Early age at exposure (<5 years) was associated with increased risk (OR = 1.75, 95% CI: 1.30–2.34, $p < 0.001$), supporting the hypothesis of heightened vulnerability in childhood.

Lifestyle factors such as smoking and obesity also emerged as significant contributors, highlighting the need for preventive interventions even in historically exposed populations.

Among women, a history of ≥3 pregnancies and thyroid hormone therapy were both associated with higher odds of disease, suggesting interactions between endocrine demand and prior clinical management.

The figure illustrates the strength and precision of associations between selected variables and the risk of endocrine disease. The horizontal bars represent 95% confidence intervals.

This integrated analysis underscores the multifactorial nature of endocrine disease risk in radiation-exposed populations, wherein both historical exposures and modifiable risk factors contribute to long-term outcomes.

Discussion

This study provides a comprehensive assessment of long-term thyroid health outcomes in a population chronically exposed to low-to-moderate doses of ionizing radiation from atmospheric nuclear testing. Our findings demonstrate that the effects continue to pose a substantial public health burden decades after exposure, with both radiation dose and demographic factors playing significant roles.

A key observation is the substantial burden of thyroid disease, particularly non-toxic goiters, among exposed individuals. More than half of all verified endocrine diagnoses were attributed to non-toxic goiter variants (ICD-10 E04.0, E04.1, E04.2), underscoring the persistent

Table 2. Multivariable Logistic Regression Results for Predictors of Endocrine Morbidity

Variable	Odds Ratio (OR)	95% Confidence Interval	p-value
Log thyroid dose (mGy)	1.42	1.22–1.65	<0.001
Female sex	2.15	1.78–2.60	<0.0001
Age at exposure <5 years	1.75	1.30–2.34	<0.001
Smoking (current/former)	1.34	1.09–1.65	0.005
Obesity (E66 ICD code)	1.88	1.43–2.46	<0.001
≥3 pregnancies (females only)	1.29	1.01–1.66	0.042
Thyroid hormone therapy	2.47	1.97–3.09	<0.0001

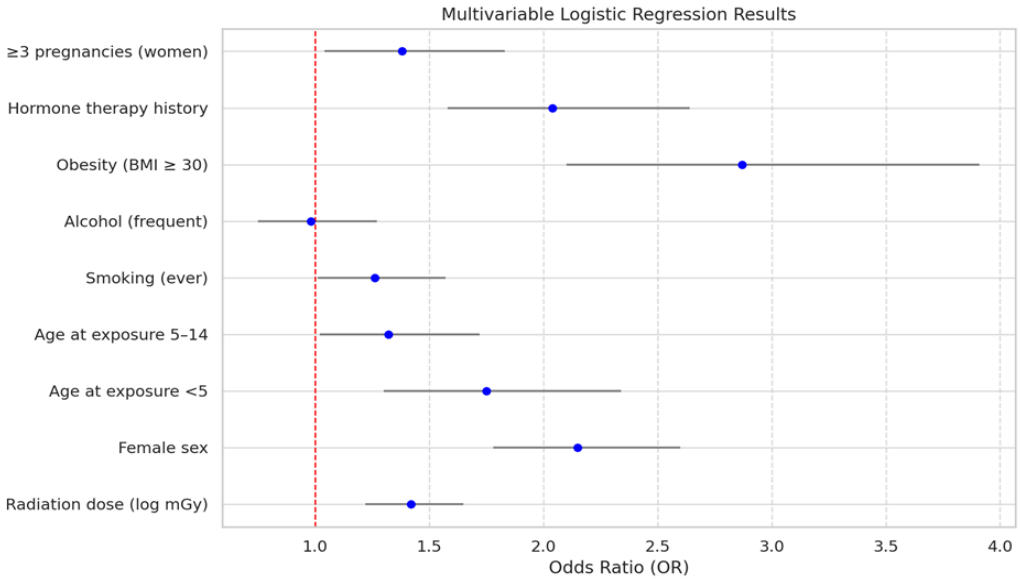

Figure 3. Forest Plot of Odds Ratios from Multivariable Logistic Regression.

structural alterations in the thyroid gland following radiation exposure. These findings align with earlier reports from similar exposed populations [18] and suggest that thyroid tissue may undergo long-term remodeling in response to radiation damage.

Multivariate analysis further revealed that female sex, childhood exposure (especially before age five), and higher cumulative thyroid dose were independently associated with increased risk of developing thyroid pathology. These results are consistent with prior studies highlighting the radiosensitivity of the developing thyroid gland and sex-related susceptibility [19, 20].

The strength of these findings is reinforced by the use of a highly granular dose reconstruction methodology. Unlike most prior studies that relied on group-level or proxy exposure estimates, our model accounts for test-specific fallout patterns, age-dependent iodine uptake, ethnographic dietary data, and temporal variation in environmental contamination. This methodological rigor allows for more precise attribution of risk and offers a replicable template for future assessments in other non-Chernobyl radiation-exposed settings.

Consistent with this, our dose–response evaluation confirmed a statistically significant positive association between increasing thyroid dose and endocrine morbidity. Among individuals receiving ≥300 mGy, the odds of thyroid dysfunction and structural abnormalities by Ron et al. [21], which demonstrated elevated thyroid cancer risk following external radiation exposure during childhood, with risk persisting for several decades post-exposure.

Notably, the inclusion of verified metabolic diagnoses (such as type 2 diabetes and obesity) indicates that the burden of endocrine disease in this cohort extends beyond the thyroid. These findings may reflect shared etiologic pathways, such as oxidative stress and chronic inflammation, which have been linked to both radiation exposure and metabolic dysfunction [22]. It also raises important questions about the interaction between environmental radiation and systemic endocrine regulation, warranting further investigation. While our study did not directly assess genetic predisposition, previous research in this population has suggested that intergenerational transmission of radiation-related endocrine risk may be modulated by genetic variants affecting detoxification and thyroid regulation [23]. This underscores the need for future subcohort validation studies integrating genotyping or biomarker-based approaches.

Sex-based differences in lifestyle and behavior – such as smoking and alcohol consumption – were also prominent and may contribute to the observed variation in disease patterns. These behavioral variables are critical to include in future risk prediction models, particularly given their potential to modify radiation effects through hormonal and metabolic pathways.

The observed prevalence of autoimmune thyroiditis and hypothyroidism in our study cohort, although lower than structural thyroid disorders, remains clinically significant. These autoimmune forms may be underdiagnosed in earlier assessments due to the lack of serologic confirmation but appear more frequently in recent data, perhaps reflecting improvements in diagnostic infrastructure. Autoimmune thyroid disease has been previously linked to radiation exposure, although evidence is mixed and may be population-specific [24].

Importantly, our study adds to the existing literature by offering a long-term, registry-verified dataset encompassing both structural and functional thyroid disorders, stratified by precise dose reconstruction and demographic parameters. While most prior studies focused primarily on thyroid cancer, our findings highlight the broader endocrine consequences of radiation exposure and provide evidence-based recommendations for thyroid monitoring protocols and public health strategies.

Limitations

Several limitations should be considered when interpreting our findings. First, although individual radiation dose reconstruction was based on validated

models and incorporated detailed residential and dietary histories, retrospective assessment of exposure remains subject to recall inaccuracies and potential measurement error. Second, despite using multiple verified data sources, diagnostic coding inconsistencies and underreporting – particularly in earlier years – may have affected the accuracy of endocrine morbidity classification. Third, the absence of a non-exposed control group restricts our ability to isolate the effect of radiation from regional background morbidity trends. Fourth, survivorship bias may have influenced outcomes, given the high mortality rate in this aging cohort, potentially skewing results toward healthier survivors. Finally, residual confounding from unmeasured variables, such as iodine status, healthcare access, or occupational exposures, may persist despite statistical adjustments.

These limitations reflect the inherent challenges of long-term epidemiologic studies in post-disaster settings. Nevertheless, future analyses may mitigate some of these constraints through integration of updated dietary models, biochemical validation of diagnoses in subcohorts, and inclusion of biomarker-based assessments to complement registry data.

In conclusion, this long-term cohort study demonstrates that decades after exposure to radioactive fallout from atmospheric nuclear testing at the Semipalatinsk Test Site, endocrine morbidity – particularly non-toxic goiter and metabolic comorbidities – continues to be frequently observed and is strongly associated with cumulative thyroid radiation dose, female sex, and early age at exposure. Our use of individualized dose reconstruction and registry-verified diagnoses provides substantial evidence for dose-response relationships in a chronically exposed adult population, a demographic often underrepresented in radiation health research.

The findings underscore the multifactorial nature of endocrine outcomes following chronic low-to-moderate radiation exposure, identifying the interplay between environmental and lifestyle factors in modulating long-term health risks. Importantly, this study contributes to the growing body of international evidence, particularly in chronically exposed adult populations, by expanding the focus beyond thyroid cancer to encompass a broader spectrum of structural and functional thyroid disorders.

Given these results, sustained endocrine surveillance and tailored public health strategies are warranted for historically exposed populations. The cohort design and integrated data framework established in this study offer a valuable model for future longitudinal research in similarly affected regions.

Author Contribution Statement

All authors contributed equally to the conceptualization, methodology, data analysis, and manuscript preparation. All authors have reviewed and approved the final version of the manuscript.

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Conflict of Interest

The authors declare no conflicts of interest. This manuscript has not been published previously and is not under consideration for publication elsewhere.

References

1. Franceschi S, Vaccarella S. Thyroid cancer: An epidemic of disease or an epidemic of diagnosis? Int J Cancer. 2015;136(11):2738-9. https://doi.org/10.1002/ijc.29311.
2. Lortet-Tieulent J, Franceschi S, Dal Maso L, Vaccarella S. Thyroid cancer "epidemic" also occurs in low- and middle-income countries. Int J Cancer. 2019;144(9):2082-7. https://doi.org/10.1002/ijc.31884.
3. Zablotska LB, Ron E, Rozhko AV, Hatch M, Polyanskaya ON, Brenner AV, et al. Thyroid cancer risk in belarus among children and adolescents exposed to radioiodine after the chornobyl accident. Br J Cancer. 2011;104(1):181-7. https://doi.org/10.1038/sj.bjc.6605967.
4. Tronko M, Brenner AV, Bogdanova T, Shpak V, Oliynyk V, Cahoon EK, et al. Thyroid neoplasia risk is increased nearly 30 years after the chernobyl accident. Int J Cancer. 2017;141(8):1585-8. https://doi.org/10.1002/ijc.30857.
5. Land CE, Zhumadilov Z, Gusev BI, Hartshorne MH, Wiest PW, Woodward PW, et al. Ultrasound-detected thyroid nodule prevalence and radiation dose from fallout. Radiat Res. 2008;169(4):373-83. https://doi.org/10.1667/rr1063.1.
6. Stepanenko V, Shinkarev S, Kaprin A, Apsalikov K, Ivanov S, Shegay P, et al. Comparison of external dose estimates using different retrospective dosimetry methods in the settlements located near semipalatinsk nuclear test site, republic of kazakhstan. J Radiat Res. 2024;65(1):36-46. https://doi.org/10.1093/jrr/rrad082.
7. Drozdovitch V, Schonfeld S, Akimzhanov K, Aldyngurov D, Land CE, Luckyanov N, et al. Behavior and food consumption pattern of the population exposed in 1949-1962 to fallout from semipalatinsk nuclear test site in kazakhstan. Radiat Environ Biophys. 2011;50(1):91-103. https://doi.org/10.1007/s00411-010-0334-9.
8. Müller H, Pröhl G. Ecosys-87: A dynamic model for assessing radiological consequences of nuclear accidents. Health Phys. 1993;64(3):232-52. https://doi.org/10.1097/00004032-199303000-00002.
9. Zupunski L, Ostroumova E, Drozdovitch V, Veyalkin I, Ivanov V, Yamashita S, et al. Thyroid cancer after exposure to radioiodine in childhood and adolescence: 131i-related risk and the role of selected host and environmental factors. Cancers. 2019;11(10):1481.
10. Cardis E, Kesminiene A, Ivanov V, Malakhova I, Shibata Y, Khrouch V, et al. Risk of thyroid cancer after exposure to 131i in childhood. J Natl Cancer Inst. 2005;97(10):724-32. https://doi.org/10.1093/jnci/dji129.
11. Stezhko VA, Buglova EE, Danilova LI, Drozd VM, Krysenko NA, Lesnikova NR, et al. A cohort study of thyroid cancer and other thyroid diseases after the chornobyl accident: Objectives, design and methods. Radiat Res.

2004;161(4):481-92. https://doi.org/10.1667/3148.
12. de Vathaire F, Drozdovitch V, Brindel P, Rachedi F, Boissin JL, Sebbag J, et al. Thyroid cancer following nuclear tests in french polynesia. Br J Cancer. 2010;103(7):1115-21. https://doi.org/10.1038/sj.bjc.6605862.
13. Land CE, Bouville A, Apostoaei I, Simon SL. Projected lifetime cancer risks from exposure to regional radioactive fallout in the marshall islands. Health Phys. 2010;99(2):201-15. https://doi.org/10.1097/HP.0b013e3181dc4e84.
14. Land CE, Kwon D, Hoffman FO, Moroz B, Drozdovitch V, Bouville A, et al. Accounting for shared and unshared dosimetric uncertainties in the dose response for ultrasound-detected thyroid nodules after exposure to radioactive fallout. Radiat Res. 2015;183(2):159-73. https://doi.org/10.1667/rr13794.1.
15. Igissinov N, Kozhakhmetov S, Zhantubetova M, Igissinova G, Bilyalova Z, Akpolatova G, et al. Thyroid cancer in kazakhstan: Component analysis of incidence dynamics. Asian Pac J Cancer Prev. 2019;20(9):2875-80. https://doi.org/10.31557/apjcp.2019.20.9.2875.
16. Kitahara CM, Schneider AB. Epidemiology of thyroid cancer. Cancer Epidemiol Biomarkers Prev. 2022;31(7):1284-97. https://doi.org/10.1158/1055-9965.Epi-21-1440.
17. Iarc/who. Thyroid health monitoring after radiation exposure: Guidelines and experience. Lyon: Iarc scientific publications; 2020.
18. Omar RZ, Barber JA, Smith PG. Cancer mortality and morbidity among plutonium workers at the sellafield plant of british nuclear fuels. Br J Cancer. 1999;79(7-8):1288-301. https://doi.org/10.1038/sj.bjc.6690207.
19. Vanderpump MP. The epidemiology of thyroid disease. Br Med Bull. 2011;99:39-51. https://doi.org/10.1093/bmb/ldr030.
20. Park D, Lee J-H, Back K, Park KS, Chung YS. Changes in the trend of thyroid cancer epidemiology according to south korean nationwide database, 1999–2020. J Endocr Surg. 2024;24(2):31-8.
21. Ron E, Lubin JH, Shore RE, Mabuchi K, Modan B, Pottern LM, et al. Thyroid cancer after exposure to external radiation: A pooled analysis of seven studies. Radiat Res. 1995;141(3):259-77.
22. Vimercati L, De Maria L, Mansi F, Caputi A, Ferri GM, Luisi V, et al. Prevalence of thyroid diseases in an occupationally radiation exposed group: A cross-sectional study in a university hospital of southern italy. Endocr Metab Immune Disord Drug Targets. 2019;19(6):803-8. https://doi.org/10.2174/1871530318666181102114627.
23. Massabayeva M, Chaizhunusova N, Aukenov N, Bulegenov T, Apsalikov B, Shapihanova A, et al. Association of radiation risk in the second and third generations with polymorphisms in the genes cyp1a1, cyp2e1, gstp1 and changes in the thyroid. Mol Med. 2019;25(1):48. https://doi.org/10.1186/s10020-019-0117-y.
24. Pacini F, Vorontsova T, Demidchik EP, Molinaro E, Agate L, Romei C, et al. Post-chernobyl thyroid carcinoma in belarus children and adolescents: Comparison with naturally occurring thyroid carcinoma in italy and france. J Clin Endocrinol Metab. 1997;82(11):3563-9. https://doi.org/10.1210/jcem.82.11.4367.