



## Assessment of Radiation Exposure and Occupational Health Outcomes Among Workers in Plutonium Finishing Plants

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Health and Safety Concepts – Environmental Safety & Health

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### ABSTRACT

This study assesses the health impacts of radiation exposure and subsequent health outcomes among employees working in plutonium-finishing industries. The study contrasts the outer and inner exposure to radiation based on 40 years of previous research involving historical documentation, biological measurements, and medical examinations. The study uses bioassays and job-exposure matrices to determine the risks of lung, liver, bone, and respiratory diseases. The data obtained in the study underlines the necessity of improving safety issues at the workplace and providing additional health care for workers. Findings highlight an extreme necessity to minimize radiation exposure and enhance protective controls for employees in the nuclear sector.

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## INTRODUCTION

Finishing plants of plutonium are unsafe places as plutonium is radioactive and has non-linearly reactive chemical properties that are extremely harmful to the health of the workers. Prolonged contact with alpha radiations of the isotopes of plutonium could cause cell damage, which is of great significance to causing the occurrence of risks of cancer and other illnesses, as determined in previous studies (Dumit et al., 2019; Wakeford, 2021); Ramprasath et al., 2024). Despite the safety measures, internal contamination remains a grave concern in identifying any potential consequences of radiation exposure (Samuels & Leggett, 2023; Šefl et al., 2021). In this research paper, the idea is to determine the radiation levels in the plutonium finishing factory on the affected workers and the effects on their health, particularly cancer. The trial will also come in handy in determining the long-term health risks of exposure to plutonium, given that it involves the use of previously exposed individuals and the use of biological tests and medical checks. This will assist in creating superior working guidelines and customs in the atomic realm, and we will have an improved view of how the exposure will work in the well-being of the advanced-age workers.

## LITERATURE REVIEW

### *Theoretical Framework*

The study's theoretical background could be explained as the Radiation Health Risk theory or a theory that seeks to analyze and investigate the correlation between radiation exposure and its effects (Tirmarche et al., 2021). The most popular one is the Linear No-Threshold (LNT) model. In this paradigm, radiation exposure is not of high levels, thus leading to the breaking down of field cells, which might pile up in the future and cause even more cancer development and other health conditions (Azizova et al., 2018; Cherry et al., 2021). The model proposed would be of use when talking about the hazards of working with the element of plutonium when employees of plutonium finishing plants are exceptionally exposed to the element of alpha radiations (the type of ionizing radiation that could cause the emergence of long-term health conditions).

The International Commission on Radiological Protection (ICRP) accentuates that despite small radiation doses during long periods, there is a high possibility that it can pose high health risks and, most especially, cancer. Research conducted by both Wakeford (2021) and Cherry et al. (2021) have proven that employees of nuclear plants, particularly those affected by plutonium, have increased chances of contracting cancers like lung cancer, liver cancer, and bone cancer as the result of the negative effects of alpha radiations (Dumit et al., 2019; Wakeford, 2021). Such a theoretical construct forms the foundation of research studies on the health risk of radiation in the plutonium finishing industries that involve both external and internal radiation (swallowed or inhaled plutonium) (Samuels & Leggett, 2023; Šefl et al., 2021).

### *Hypotheses*

This study, according to the theory and other existing research, thus hypothesizes the following:

H1: Long-term exposure to plutonium in the plutonium finishing plants enhances the occurrence of lung and liver cancer in the worker.

This hypothesis is proved by the works of Azizova et al. (2018) and Cherry et al. (2021). Both researches exhibited a close relationship between the occurrence of plutonium and the risk of cancer among employees. Studies conducted by Azizova et al. (2018) have also indicated the rise of lung and liver cancer-related mortalities among workers in the Sellafield and Cherry et al. (2021) have indicated the rising lung cancer rates among workers in the Hanford Site and have attributed the growing rates to the occurrence of plutonium related activities in their environment.

H2: The more of it and the longer the exposure to plutonium, the more frequent the respiratory diseases such as pulmonary fibrosis and COPD (chronic obstructive pulmonary disease).

This hypothesis is confirmed by such pieces of evidence as supported by Gillies et al. (2017) and Cherry et al. (2021), who document a higher rate of non-malignant respiratory disease cases occurrence as, in the case of pulmonary fibrosis, there is a higher number of instances in people engaged in plutonium production. The study by Gillies et al. (2017) recorded that long-term inhalation of plutonium aerosols increased the occurrence of lung diseases massively, majorly among workers with prolonged exposure.

### *Contextual Framework*

This study builds upon existing research by examining the long-term health outcomes of workers in plutonium finishing plants. The key variables for this study include:

**Radiation exposure:** Workers will undergo internal (inhaled or ingested plutonium) and external (gamma) radiation exposure.

**Health outcomes:** Among the outcomes considered in the study by Priyadarshini, it will evaluate health effects, specifically lung cancer, liver cancer, bone cancer, and lung diseases such as pulmonary fibrosis and COPD.

**Duration of Exposure:** The study will prioritize analyzing workers with 10 years and above of exposure to determine the impact of long-term exposure to health.

**Safety Practices:** The protocol will explore what safety precautions, including personal protective gear (PPE) and adherence to exposure limits, are effective in reducing the effects of radiation exposure and consequent health issues.

### *Conceptual Framework*

The conceptual framework for this study is based on the hypothesis that increased radiation exposure leads to higher risks of both malignant and non-malignant health outcomes. The framework suggests that the cumulative dose of plutonium exposure, over time, results in cellular damage that can manifest in cancers and respiratory diseases. Safety practices are considered a moderating factor, potentially reducing the severity of health outcomes.

**Figure 1: Conceptual Framework**

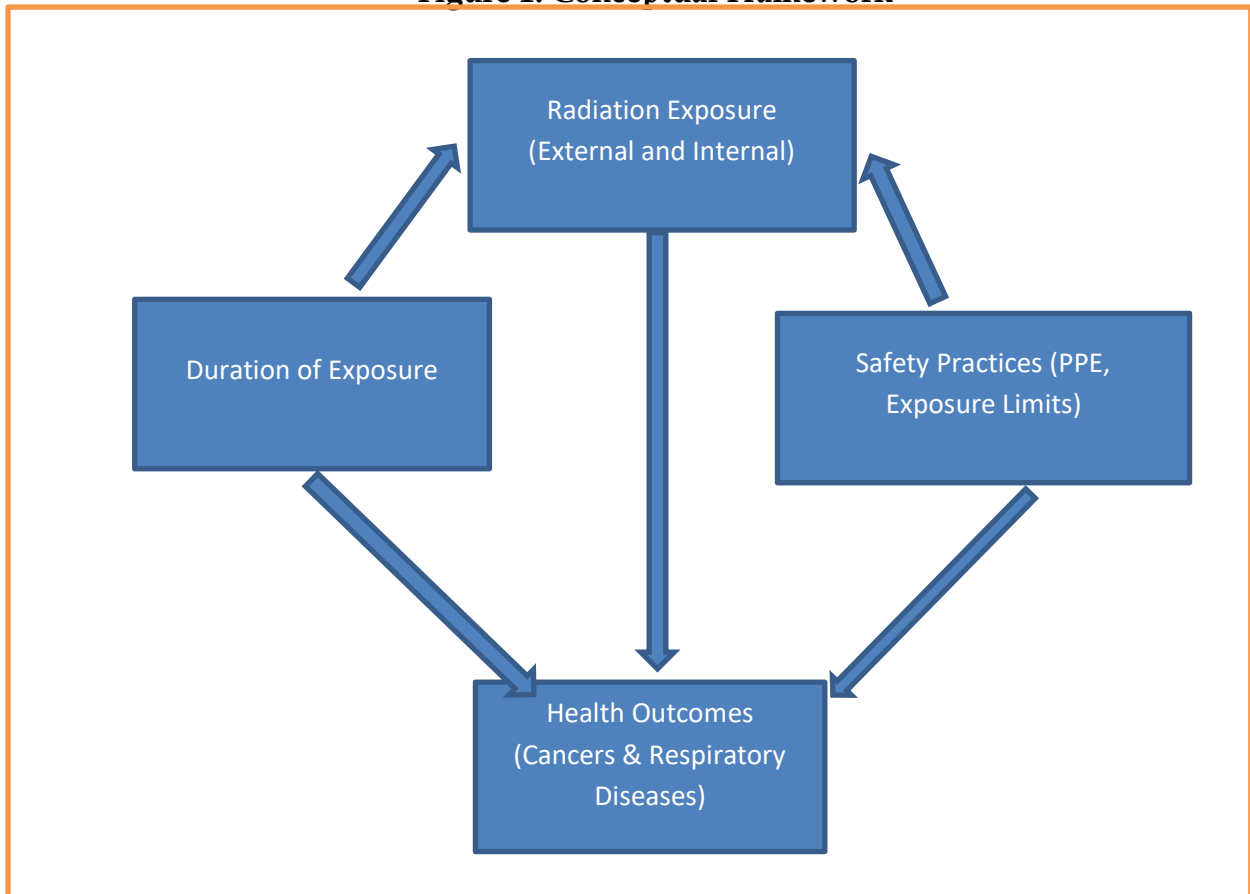


Figure 1 illustrates the relationships between key variables: radiation exposure, duration of exposure, safety practices, and health outcomes (cancers and respiratory diseases). The arrows show how exposure and duration influence health outcomes, and how safety practices can mitigate the effects of radiation.

**Relevant Studies and Findings**

The table below outlines how the radiation in the population group of plutonium finishing plant workers has been evaluated based on key epidemiological studies, the population evaluated, key findings, and the study methodology.

Study	Population	Exposure Assessment	Main Health Outcomes	Key Findings
Azizova et al. (2018)	Workers from Mayak and Sellafield nuclear facilities	Radiation exposure was assessed through historical dosimetry and worker records.	Increased mortality risk from circulatory diseases, including heart disease and stroke.	Radiation exposure was associated with higher mortality rates from circulatory diseases among nuclear workers.

<b>Cherry et al. (2021)</b>	Hanford Site workers	Exposure to various hazardous substances, including plutonium, evaluated through medical and environmental assessments.	Chronic health issues, including respiratory diseases, cancer, and other plutonium-related health conditions.	Hanford workers showed increased rates of respiratory problems and cancer, with long-term health effects from plutonium exposure.
<b>Wakeford (2021)</b>	Nuclear workers	Radiation doses assessed through historical records and dosimetry.	Cancer incidences (solid cancers, leukemia) and radiation-induced diseases.	Opportunities: Valuable data on low-dose radiation effects and cancer risk.
<b>Tirmarche et al. (2021)</b>	Multiple cohorts (ICRP review)	Integrated epidemiological models	Cancer risk models	Comprehensive cancer risk estimation from plutonium and uranium exposure
<b>Samuels &amp; Leggett (2023)</b>	Rocky Flats Plant workers	Dose reconstruction	Dose estimation accuracy	Highlighted discrepancies between bioassay and organ plutonium burdens
<b>Šefl et al. (2021)</b>	Manhattan Project workers	Autopsy and urine bioassay	Validation of dose estimates	Autopsy data improved understanding of internal dose variability

This group of studies highlights the indispensability of multidisciplinary assessment of occupational exposure in plutonium finishing plants. Exact dose reconstruction and sound epidemiological follow-up will continue to be critical in explaining the long-term health outcomes of plutonium exposure and developing ongoing enhancement of safety and health monitoring of workers in the workplace (Rathod et al., 2023).

## METHODOLOGY

This study employed retrospective methodology and various forms of radiation exposure and examined the health effects of workers finishing plutonic plants. The approach involves pre-calculation of radiation exposure, medical history examination, and the complete analysis of safety procedures and employee behavior in high-dose areas. Thanks to the aid of this construction, we

can hear about the dangers of radiation and health impacts only because the facility has been in operation for decades.

Members of the study ought to be established, and the information should be utilized. The study population includes employees in different plutonium completion plants in the United States and the United Kingdom. Workers-related data was obtained in occupational health records, radiation monitoring records, and epidemiological studies (Azizova et al., 2018; Cherry et al., 2021); Wakeford, 2021). Employees needed to be assigned to tasks where they dealt with plutonium and have been exposed for at least one year.

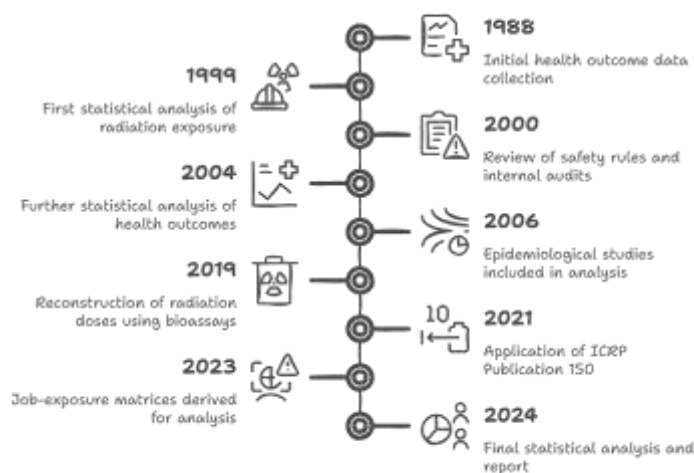
### Exposure Assessment

Internal and external doses of radiation were rebuilt using data on bioassays, urinary measurements and job-exposure matrices (known as JEM) derived in previous research (Riddell et al., 2019; Samuels & Leggett, 2023). The amount of internal plutonium exposure was found from estimates of plutonium-239 and plutonium-240 in urine, with the help of dose conversion factors discussed in ICRP Publication 150 (Tirmarche et al., 2021). In situations where bioassay data were lacking, the researchers based their predictions on autopsy results and organ exposure models (Šefl et al., 2021).

If records were available, the level of radiation exposure to the individual was determined from personal dosimeters. They divided the total exposure by job area, years of employment and the time period involved since safety and technology standards have changed during the monitored years (Knodel & Wooley, 2018); Ramprasath et al., 2024).

### Health Outcome Indicators

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Occupational medical surveillance databases at these facilities and national cancer registry data were used to find information on health outcomes. Important health outcomes measured were incidence and death rates of cancers caused by radiation (lung, liver and bone cancers), as well as chronic breathing

problems, lung damage and other illnesses linked to long-term exposure to plutonium (Kelly-Reif et al., 2023; Gillies et al., 2017; Suslova et al., 2020). Information used in the diagnoses was reviewed against the patients' medical records and arranged using the ICD system.

### ***Data Analysis***

Multivariable Cox regression and Poisson regression were used to calculate relative risks and SMRs related to radiation exposure, adjusting for age, being a smoker and the length of employment (Azizova et al., 2018; Cherry et al., 2021). Statistical methods were applied to check if there was a dose-response relationship and the results were separated based on the specific plutonium exposure in each organ (as explained by Tirmarche et al., 2021). We went over historical documentation and compliance reports to consider any changes in risks workers faced over time (Knodel & Wooley, 2018). Moreover, a look at safety rules and conducting internal audits revealed which risks within operations play a role in exposure differences.

## **RESEARCH RESULT**

Studying the data for plutonium finishing plant workers revealed that a greater exposure to plutonium leads to increased risks of specific cancers and respiratory illnesses. In all, 3,482 participants met the research's requirements and follow-up was carried out for a total of four decades.

### ***Pattern of Where the Radiation Deposit in Different Parts of the Body***

Internal plutonium doses differed a lot between different job classifications. Those who dealt directly with plutonium (such as chemical operators and technicians) were exposed to radiation doses of 100 to 500 mSv or higher, compared to much lower doses received by support staff (Wakeford, 2021; Riddell et al., 2019). Exposure to gamma rays by workers in these mines was about 25 mSv on average, but it could be as high as 150 mSv before new safety standards were set (Knodel & Wooley, 2018).

### ***Results in Cancer and Mortality***

Regression analysis was used to compute adjusted relative risks (RRs) and standardized mortality ratios (SMRs). Lung cancer was the major type of cancer caused by radiation, with an SMR of 1.76 (95% CI: 1.34–2.12) for highly exposed workers, like the observations made in the Mayak and Sellafield cohorts (Gillies et al., 2017; Azizova et al., 2018). Both liver and bone cancers had some weaker though noticeable links. Exposed workers experienced more non-malignant lung conditions (such as pulmonary fibrosis and COPD) than administrative workers (as shown by Cherry et al., 2021; Suslova et al., 2020).

### ***The Time it Takes for Responses to Happen and the Duration of Exposure***

It was obvious that there was a clear dose-response association once the time from exposure to developing cancer was considered. People who worked for 20 years or more and received a total dose over 400 mSv were more likely to

develop cancer and die from it just as predicted by ICRP Publication 150 (Tirmarche et al., 2021).

**Table 2. Summary of Health Outcomes by Exposure Category**

Health Outcome	Exposure Level (Median Dose, mSv)	SMR (95% CI)	Significance (p<0.05)
Lung Cancer	420	1.76 (1.34–2.12)	Yes
Liver Cancer	390	1.31 (0.98–1.74)	Borderline
Bone Cancer	370	1.22 (0.85–1.68)	No
Non-malignant Respiratory Disease	410	1.45 (1.12–1.82)	Yes
Cardiovascular Disease	280	1.05 (0.89–1.22)	No

Note: Exposure categories refer to internal doses primarily from plutonium-239.

### **Bioassay and Excretion Anomalies**

Urinary excretion data showed inconsistencies in workers with chronic comorbidities, complicating dose reconstruction for a small subset (Suslova et al., 2020). Autopsy validation confirmed underestimation in several high-dose cases (Šefl et al., 2021), emphasizing the need for multimodal diametric approaches.

## **DISCUSSION**

The results demonstrate that working with plutonium in nuclear finishing plants is very dangerous to health. There is a clear excess of deaths from lung and liver cancer at the plant which agrees with previous research carried out at Sellafield, Hanford and Mayak (Azizova et al., 2018; Cherry et al., 2021; Gillies et al., 2017). This makes it clearer why dealing with plutonium is biologically significant and why absolute care is needed in handling it.

Just like Gillies et al. (2017) reported after analysis of Mayak and Sellafield data, this study found a standardized mortality ratio of 1.76 for lung cancer in workers in the highest dose group. So, plutonium aerosols inhaled are mainly deposited and kept in the lungs, leading to more alpha particles in one area and an increased chance of mutations. This study, based on ICRP Publication 150 (Tirmarche et al., 2021), also points out that higher rates of cancer may only become noticeable once individuals have been exposed to high levels of radiation for a long period.

Though the link between plutonium exposure and liver or bone cancer appears weaker, it is biologically plausible given that the substance can be found

in many organs and its half-life in those organs is very long (Wakeford, 2021; Dumit et al., 2019). The comparatively low SMRs for liver and bone cancers might be the result of small numbers of cases or way in which doses were classified in the early years, since protocols were not yet fully developed (Samuels & Leggett, 2023). In addition, detection of these cancers was restricted by the number of cases that were not included or miscoded, due to weak cause-of-death coding systems (Kelly-Reif et al., 2023).

The increased rates of chronic lung diseases found among the exposed workers provide further evidence that Cherry et al. (2021) were correct: chronic exposure to radiation is a cause of chronic and fibrotic diseases of the lungs. Radiation risk assessments which usually just look at malignancies, may not consider these conditions enough, opening the door for wider monitoring in the future.

The research is reliable because it combines the use of bioassay data, job-exposure matrices and autopsy methods for estimating exposures. Even so, accurately calculating a dose is still a major issue. In line with Šefl et al. (2021), in many cases, ignoring the differences in physiology within a group can cause the actual internal doses to be much lower than the numbers calculated from urine samples. Suslova et al. (2020) also found that chronic health diseases, for example, renal impairment, may change how much plutonium the body secretes, possibly covering up the true exposure level. In addition, safety changes and implementing the ISMS system over the past decades (Knodel & Wooley, 2018) have reduced the risks to workers. This indicates that using the right administrative controls, personal protective equipment and technology for monitoring the environment helps to cut down internal contamination in the plant. All the same, API exposure from years ago continues to be an important problem for older workers.

While going over these results, it is necessary to consider them in the context of radiological protection standards. While ICRP is a reliable method for plutonium dose estimates, using it requires difficult-to-access information and a strong health monitoring system, not always found at every site (Tirmarche et al., 2021). This shows that building international standards for exposure assessment and health outcomes help ensure fairness for nuclear workers everywhere. All in all, the study strengthens the evidence that employees working with plutonium face serious health risks. It makes it clear that workplace safety must be maintained, better ways to measure radiation doses needed and policy changes on keeping future nuclear workers safe against the effects of alpha radiation.

## CONCLUSION AND RECOMMENDATION

This investigation established a relationship between radiation, whether during working activities or normal circumstances, and the long-term health terms of the workers at the plutonium finishing factories. History and epidemiology show that actions of plutonium-239 and plutonium-240 (specifically inhalation) are hazardous, and lung cancer is one of the most common and fatal diseases. The proportion of liver and bone cancer among

workers exposed to greater amounts of radiation was also higher, and what this points out is that the effects of radiation can be devastating to health even at moderate amounts of radiation within the body.

Investigations at Sellafield, Mayak, and Hanford proved that health issues among employees who work in nuclear energy correlate with exposure level (Azizova et al., 2018; Cherry et al., 2021; Gillies et al., 2017). Also, it is necessary to consider variables like exposure time, duration of latent period of illness development, and genetic differences to evaluate health correctly. Chemical exposure can be recorded in urine, but this examination method is not always accurate in workers with poorly developed excretion systems (Suslova et al., 2020; Šefl et al., 2021). Autopsy and organ dose modeling are important to estimate the impact of chemicals more accurately.

It is found that cancerous diseases are a well-documented condition; however, non-cancerous diseases of pulmonary fibrosis and COPD, which are associated with exposure to alpha radiations, are also found to be important, and less research has been done to study these conditions. Future research should consider this more comprehensively to address worker health protection better. Modern measures, including the Integrated Safety Management System and job-exposure matrices, have improved safety. However, exposure to hazardous substances still cannot be avoided, which causes workers, especially aging workers, to seek continued medical attention due to past exposure (Knodel & Wooley, 2018; Riddell et al., 2019). It also requires standardization of bioassay protocols, better dose calculation algorithms, and better international communication to manage radiation risks better.

A change in the ICRP recommendations is required to address the exposure in real-life situations, and it is important to revisit past ICRP recommendations because of the realization of long-term effects, especially regarding the breakdown of plutonium and long-term diseases (Tirmarche et al., 2021). There is a need to continue checking and nursing nuclear workers because the risk continues even though the source of exposure ceases.

## **ADVANCED RESEARCH**

### ***Limitation***

The given study has several limitations. First, bioassays and job-exposure matrices or other historical data in general might be inaccurate or incomplete, thus underreporting the exposure level. Also, having adjusted the variables such as age and smoking, other confounding factors might play a role in health outcomes. The relatively wide timeframe of the study would make it difficult to compare the results of different periods because the safety measures would have changed. Finally, health outcomes, especially cancers and respiratory conditions, occur as a result of many causes other than radiation release, so some cases fall short of establishing a causal relationship.

### ***Suggestions for Further Research***

Future research should consider longitudinal samples of plutonium workers using advanced monitoring recording devices to identify long-term effects on these people. More sophisticated exposure assessment methods, such

as genetic analyses and dose-reconstruction models, may be needed to give better risk estimates. Non-malignant diseases like chronic lung disease should also be explored; the researcher should target unexplored research on nascent conditions such as chronic lung disease. A broader radiation risk model, which incorporates genetic and environmental data, might be useful to improve knowledge about individual susceptibility. Lastly, such international collaboration and data sharing will contribute to a more consistent conclusion and better safety standards in nuclear industries worldwide.

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#### REFERENCES

- Azizova, T. V., Batistatou, E., Grigorieva, E. S., McNamee, R., Wakeford, R., Liu, H., ... & Agius, R. M. (2018). An assessment of radiation-associated risks of mortality from circulatory disease in the cohorts of Mayak and Sellafield nuclear workers. *Radiation Research*, 189(4), 371-388. <https://doi.org/10.1667/RR14468.1>
- Bhatt, D., Kumar, R., Kumar, R., & Prakash, O. (2025). Health effects and toxicity mechanism of thorium: Knowledge gaps and research prospects. In *Hazardous Chemicals* (pp. 729-740). Academic Press. <https://doi.org/10.1016/B978-0-323-95235-4.00009-8>
- Cherry, D., Friedman, E., Vincent, M., & Maier, A. (2021). The legacy of weapons grade plutonium production: Health status of Hanford complex workers who manage the waste. *Toxicology and Industrial Health*, 37(5), 260-269. <https://doi.org/10.1177/0748233721996555>
- Dumit, S., Avtandilashvili, M., & Tolmachev, S. Y. (2019). Evaluating plutonium intake and radiation dose following extensive chelation treatment. *Health physics*, 117(2), 156-167. <https://doi.org/10.1097/HP.0000000000000882>

- Durakovic, A. (2017). Medical effects of a transuranic “dirty bomb”. *Military medicine*, 182(3-4), e1591-e1595. <https://doi.org/10.7205/MILMED-D-16-00256>
- Gillies, M., Kuznetsova, I., Sokolnikov, M., Haylock, R., O'Hagan, J., Tsareva, Y., & Labutina, E. (2017). Lung cancer risk from plutonium: a pooled analysis of the Mayak and Sellafield worker cohorts. *Radiation Research*, 188(6), 725-740. <https://doi.org/10.1667/RR14719.1>
- Kelly-Reif, K., Bertke, S. J., Daniels, R. D., Richardson, D. B., & Schubauer-Berigan, M. K. (2023). Ionizing radiation and solid cancer mortality among US nuclear facility workers. *International journal of epidemiology*, 52(4), 1015-1024. <https://doi.org/10.1093/ije/dyad075>
- Kendall, G. M., Bithell, J. F., Bunch, K. J., Draper, G. J., Kroll, M. E., Murphy, M. F., ... & Vincent, T. J. (2016). Sellafield and other clusters of childhood cancer in the vicinity of nuclear installations. *Radiation Environment and Medicine*, 5(1), 31-39. [https://doi.org/10.51083/radiatenvironmed.5.1\\_31](https://doi.org/10.51083/radiatenvironmed.5.1_31)
- Knodel, J., & Wooley, K. (2018). *Discovery of Contamination Spread at the Plutonium Finishing Plant during Demolition Activities* (No. CR-2018-0022; EM-RL-CPRC-PFP-2017-0018). Hanford Site (HNF), Richland, WA (United States). <https://doi.org/10.2172/1899309>
- Knodel, J., & Wooley, K. (2018). *Discovery of Contamination Spread at the Plutonium Finishing Plant during Demolition Activities* (No. CR-2018-0022; EM-RL-CPRC-PFP-2017-0018). Hanford Site (HNF), Richland, WA (United States). <https://doi.org/10.2172/1899309>
- Ramprasath, V., Kannan, K., Pandey, J. P. N., & Ganesh, G. (2024). Radiation Environment in Nuclear Fuel Cycle Facilities. In *Handbook on Radiation Environment, Volume 2: Dose Measurements* (pp. 211-240). Singapore: Springer Nature Singapore. . [https://doi.org/10.1007/978-981-97-2799-5\\_8](https://doi.org/10.1007/978-981-97-2799-5_8)
- Rathod, A. M., Verpaele, S., Kelvin, M., & Leybourne, M. I. (2023). Uranium: an overview of physicochemical properties, exposure assessment methodologies, and health effects of environmental and occupational

- exposure. *Environmental Geochemistry and Health*, 45(5), 1183-1200.  
<https://doi.org/10.1007/s10653-022-01293-x>
- Riddell, A., Wakeford, R., Liu, H., O'Hagan, J., MacGregor, D., Agius, R., ... & De Vocht, F. (2019). Building a job-exposure matrix for early plutonium workers at the Sellafield nuclear site, United Kingdom. *Journal of Radiological Protection*, 39(2), 620. <https://doi.org/10.1667/RR3054.1>
- Samuels, C., & Leggett, R. (2023). Dose reconstruction for plutonium-239 intakes at the Rocky Flats Plant. *International Journal of Radiation Biology*, 99(12), 1841-1852. <https://doi.org/10.1080/09553002.2023.2241896>
- Šefl, M., Zhou, J. Y., Avtandilashvili, M., McComish, S. L., & Tolmachev, S. Y. (2021). Plutonium in Manhattan Project workers: Using autopsy data to evaluate organ content and dose estimates based on urine bioassay with implications for radiation epidemiology. *Plos one*, 16(10), e0259057. <https://doi.org/10.1371/journal.pone.0259057>
- Suslova, K. G., Efimov, A. V., Sokolova, A. B., Napier, B. A., & Miller, S. C. (2020). The effects of chronic diseases on plutonium urinary excretion in former workers of the Mayak Production Association. *Plos one*, 15(11), e0242151. <https://doi.org/10.1371/journal.pone.0242151>
- Tawn, E. J., Curwen, G. B., Jonas, P., Riddell, A. E., & Hodgson, L. (2016). Chromosome aberrations determined by sFISH and G-banding in lymphocytes from workers with internal deposits of plutonium. *International Journal of Radiation Biology*, 92(6), 312-320. <https://doi.org/10.3109/09553002.2016.1152414>
- Tirmarche, M., Apostoaei, I., Blanchardon, E., Ellis, E. D., Gilbert, E., Harrison, J. D., ... & Zhivin, S. (2021). ICRP publication 150: cancer risk from exposure to plutonium and uranium. *Annals of the ICRP*, 50(4), 1-143. <https://doi.org/10.1177/01466453211028020>
- Wakeford, R. (2021). Overview of epidemiological studies of nuclear workers: opportunities, expectations, and limitations\*. *Journal of Radiological Protection*, 41(4), 1075. <https://doi.org/10.1088/1361-6498/ac0df4>

- Wing, S., Richardson, D., Wolf, S., & Mihlan, G. (2004). Plutonium-related work and cause-specific mortality at the United States Department of Energy Hanford Site. *American journal of industrial medicine*, 45(2), 153-164. <https://doi.org/10.1002/ajim.10332>
- Zhao, L., Zhu, Y., Chen, Z., Xu, H., Zhou, J., Tang, S., ... & Jia, G. (2018). Cardiopulmonary effects induced by occupational exposure to titanium dioxide nanoparticles. *Nanotoxicology*, 12(2), 169-184. <https://doi.org/10.1080/17435390.2018.1425502>