REVIEW ARTICLE

Proximity of Maternal Residences to Nuclear Power Plant, Prenatal Exposure to Ionising Radiation and Its Effect on Pregnancy Outcomes: A Systematic Review

Aisyah Sofia Hamzah[1], Norhidayah Ahmad[1,*]

[1]Department of Biomedical Science, Kulliyyah of Allied Health Sciences, International Islamic University Malaysia, 25200 Kuantan, Pahang, Malaysia

Keywords:
Ionising radiation; industrial activity; nuclear power plant; pregnancy outcomes

ABSTRACT

Background: The radiation issue has long been a subject of controversy and debate, particularly on acceptable exposure levels and the potential health impacts on the public, especially vulnerable groups like pregnant women. The proximity of residency to sources of this physical hazard can significantly contribute to elevated levels of radiation exposure. Therefore, this study aims to systematically review the published articles on the effects of pregnancy outcomes resulting from maternal exposure to ionizing radiation (IR) from nuclear power plants (NPP) or mines and to investigate the relationship between the proximity of maternal residences to NPPs or mines and the associated risk of adverse pregnancy outcomes. **Methods:** This study followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. Articles were sourced from PubMed, ProQuest, and Scopus databases. The inclusion criteria encompassed:(i) articles published in English with full-text availability and (ii) observational studies that reported on IR exposure from industrial areas and its effects on pregnancy. Articles were excluded from this study if they did not report the observed exposure and health outcomes or if they involved a non-human study. The Critical Appraisal Tool (CCAT) version 1.4 was used for the quality assessment. **Results:** 215 articles were screened, with 8 full-text articles selected for final evaluation. Among these, 6 articles examined IR exposure from the NPP, while 2 articles investigated the radiation exposure from uranium plants. The distance between residential homes and the NPPs or uranium plants ranged from 0.8 to 50km. The observed adverse pregnancy outcomes included birth defects, premature birth, pregnancy loss, and low birth weight. 5 articles recorded high quality (score range from 80 – 90%) and only 3 articles recorded acceptable quality (score range from 55- 75%). **Conclusion:** Our findings reveal no association between the proximity of residency to NPP or uranium plants with adverse pregnancy outcomes. This review was able to enhance the understanding of the observed relationship, despite the limited articles to provide a defined conclusive. Future studies are recommended to focus on the effects of radiation on the exposure of specific trimester windows and determine the biological mechanisms underlying the adverse pregnancy outcomes.

INTRODUCTION

Radiation is classified as a physical hazard that can cause detrimental effects to human health by causing chemical changes in human DNA and may result in abnormal cell growth (ILO, 2024). Radiation can be divided into two types, which are non-ionising radiation (NIR) and ionising radiation (IR) (USNRC, 2020). NIR does not have enough energy to remove electrons from atoms and the energy will be accumulated in the materials it passes, such as visible light, microwaves and radio waves. Meanwhile, IR has enough energy to remove electrons from the atom using the accumulated energy such as cosmic rays, x-rays and radiation from radioactive materials (ILO, 2024; USNRC, 2020).

IR has numerous applications across various industries, including energy production, manufacturing, medicine and research (ILO, 2024). People may exposed to radiation, whether from medical procedures, occupational factors or environmental sources. The exposure to radiation to certain vulnerable groups has raised public health concerns. Radiation exposure to pregnant women during the gestational period can jeopardize the health and safety of the developing fetus. The International Commission on Radiological Protection (ICRP 103) recommends a radiation protection limit of 1 mSv/year for pregnant workers to protect the developing fetus, which is the same as the annual limit for public exposure (ICRP, 2007). Maternal exposure to IR during the gestational period may cause adverse pregnancy outcomes, such as spontaneous abortion, intrauterine growth restriction, mental retardation, birth defects and leukaemia (Tsou et al., 2019).

To date, there is limited research available on discussing the effect of pregnancy outcomes due to the radiation generated from industries of nuclear power plants (NPP) or mines (Wang, 2009). The previous literature studied the impact of high-dose of IR on the survivors of the catastrophes of Hiroshima and Nagasaki and the

* *Corresponding author.*
E-mail address: hidayahahmad@iium.edu.my

Chernobyl meltdown, but the health effects of the daily exposure level to IR among humans are limited and only focused on the animal effect (Mangones, 2013). The exposure to radiation from industrialization has become a public health concern as the radiation from these sources may add up to 80% of the yearly dose of radiation level to the nearest population, whereas the remaining 20% comes from various sources such as medical, commercial and industrial activities (World Nuclear Association, 2017). Hence, this study aimed to systematically review the published articles on the effects of pregnancy outcomes resulting from maternal exposure to ionizing radiation (IR) from nuclear power plants (NPP) or mines. It also aims to investigate the relationship between the proximity of maternal residences to NPPs or mines and the associated risk of adverse pregnancy outcomes.

METHODS

Study Design

This study was carried out based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guideline. There is a 27-item checklist and a four-phase flow diagram (as shown in Figure 1) in the PRISMA Statement (Moher et al., 2009).

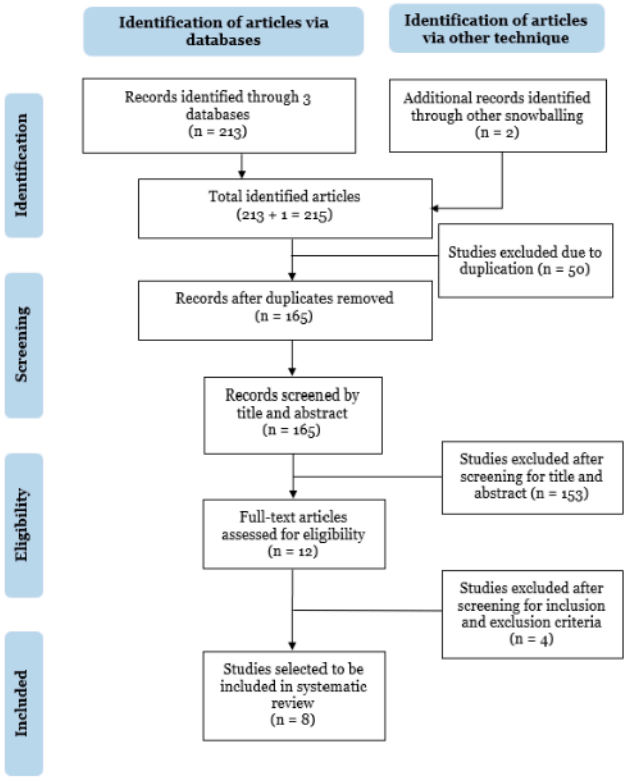

Figure 1: PRISMA Flow Diagram for the selection of articles

Article Search Strategy

The search strategy of the research paper was conducted by referring to three online databases (PubMed, ProQuest and Scopus). The Boolean operators of the connective terms such as AND, OR, and NOT have been used in the search strategy to get comprehensive results. A specific search string was built: (pregnancy OR "pregnant women" OR "pregnant woman" OR fetus OR foetus) AND (mining OR "processing plant" OR "nuclear plant" OR "power plant" OR "nuclear facilities") AND radiation AND (effect OR outcome). Other relevant articles were also manually searched by checking the reference lists of selected articles using the snowballing technique.

Selection Criteria

From the identified articles, studies that met the following eligibility criteria were selected based on; (i) articles published in the English language with full-text access; (ii) human epidemiological studies with several study designs (case-control, cohort and cross-sectional studies) and (iii) studies reported on IR exposure from the NPP or mines and the effect on pregnancy. Retrieved articles that did not meet these criteria were excluded from the list. Only the final shortlisted articles went through the data analysis process and quality assessment procedures.

Article Screening and Data Extraction

The selected articles were evaluated by two independent reviewers for the relevance of the selection and any disagreement between reviewers was discussed. The article selection involves four levels as outlined in the PRISMA guideline.

For the first level of screening, the titles and abstracts of the articles were screened and the duplicates of research articles between databases were removed. The articles that passed the first level of screening were further screened based on the eligibility criteria of inclusion and exclusion. Then, the data from the selected articles were extracted systematically. Study characteristics that comprised the information of the year of study and country, study design, sample size, source of radiation, observed pregnancy outcomes and the major findings were recorded in Table 1.

Article Evaluation and Critical Appraisal

The evaluation of the selected articles was performed with the use of Crowe Critical Appraisal Tool (CCAT)

version 1.4. It has 22 items that are divided into eight categories (preliminaries-title/abstract, introduction, design, sampling, data collection, ethics, results and discussion) to evaluate the quality of the articles. Each category can only be scored as a whole number (from 0 to 5) and the total scores will be converted into a percentage, which the value of percentage can be categorised as; poor (≤ 50%), acceptable (51–79%) and high quality (≥ 80%).

RESULTS

Bibliographic Search

The searches identified 213 potentially relevant articles from three online databases (98 articles from PubMed, 74 articles from Scopus and 41 articles from ProQuest) and only two articles were obtained from snowballing technique. After eliminating the duplicate articles, the articles were screened based on the title and followed by the abstract, which resulted in 153 articles being excluded (irrelevant to the aim and criteria of the study). Only 12 articles were eligible for full-text screening. At this stage, four articles were further excluded as they were not primary studies that explored the exposure of IR in pregnant women. Finally, only eight articles were included in this review.

Overview of the Selected Articles

Characteristics of the selected articles are presented in Table 1. The selected articles have been published from 1992 to 2020. Among eight selected articles, two were case-control studies (Gong et al., 2016; Shields et al., 1992), two were cohort studies (Dummer et al., 1998; Queisser-luft et al., 2011) and four were cross-sectional studies (Wang et al., 2010; Mangones et al., 2013; Jirova et al., 2020; Slama et al., 2008). Out of eight, three articles were conducted in the United States (US) (Gong et al., 2016; Shields et al., 1992; Mangones et al., 2013), one in Taiwan (Wang et al., 2010), one in the United Kingdom (UK) (Dummer et al., 1998), one in Czechia (Jirova et al., 2020), one in Germany (Queisser-luft et al., 2011) and one in France (Slama et al., 2008). All the selected articles involved a large population sample size (n > 1000).

Proximity of Maternal Residences to Nuclear Power Plants or Mines

All selected studies defined the study area as below a 50 km radius from maternal residency to NPP or mines, except only one study that did not specify the distance that they adopted (Slama et al., 2008). Six articles examined the exposure of IR from NPP (Wang et al., 2010; Queisser-luft et al., 2011; Mangones et al., 2013; Dummer et al., 1998; Slama et al., 2008; Gong et al., 2016), whereas two articles assessed the pregnancy outcomes due to exposure to IR from uranium processing plants (mines) (Jirova et al., 2020; Shields et al., 1992).

Effects of Ionising Radiation on Adverse Pregnancy Outcomes

Adverse pregnancy outcomes refer to health complications or unfavourable events affecting the mother, newborn or both during gestation, labor and delivery, or the postpartum period (Tadese et al., 2022). These complications can range from mild to severe and may have short or long-term effects on maternal and neonatal health such as spontaneous abortion, stillbirth, birth defects and intrauterine growth restrictions. In this review, four articles observed multiple adverse pregnancy outcomes such as stillbirth, premature birth, low birth weight (LBW) and birth defects (Wang et al., 2010), birth defects, LBW and prematurity (Mangones et al., 2013), spontaneous abortions and birth defects (Jirova et al., 2020) and miscarriage and LBW (Slama et al., 2008). Meanwhile, four articles only observed single outcomes such as birth defects (Queisser-luft et al., 2011; Shields et al., 1992), stillbirths (Dummer et al., 1998) and LBW (Gong et al., 2016). Seven of the selected articles did not obtain any associations except for Shields et al. (1992) found an association between radiation exposure and birth defects.

Quality of the Selected Articles

The quality assessment (QA) of the selected articles was assessed based on the Crowe Critical Appraisal Tool (CCAT) version 1.4 as shown in Table 2. All the articles clearly described their objective, defined the outcomes, reported results and had conclusions that supported their results. From all the selected studies, the highest percentage of QA was recorded by Slama et al. (2008) at 90%. This is followed by Queisser-luft et al. (2011), Wang et al. (2010), Gong et al. (2016), and Mangones et al. (2013) which recorded the percentage of QA at 85, 83, 80, and 80%, respectively. Meanwhile, the studies by Dummer et al. (1998) and Shields et al. (1992) recorded a percentage between 70 – 79% and the lowest recorded by Jirova et al. (2020) at a percentage of 55%. Despite Jirova et al. (2020) being the lowest figure, this study was still deemed acceptable and included in this review.

Table 1: Characteristics of selected articles on radiation exposure and adverse pregnancy outcomes

No.	Author and year of study; Country	Title of study	Study design; Research data	Source of radiation; Radiation exposure level	Observed outcomes; Sample size	Principal findings
[1]	Jirova et al. (2020); Czechia	Incidence of spontaneous abortions and congenital anomalies in the vicinity of a uranium processing plant	Cross-sectional study; 19 years of medical records (1994 – 2013)	UPP; N/A	Spontaneous abortions and congenital anomalies; Not specified	- Distance from residential regions to the UPP (mines) is within 20 km - Non-significant increment of spontaneous abortions (p>0.05) and birth defects (p = 0.05) in the vicinity
[2]	Gong et al. (2017); US	Maternal residential proximity to nuclear facilities and low birth weight in offspring in Texas	Case-control study; 12 years of medical records (1996 – 2008)	NPP; N/A	Low birth weight; 94,106	- Distance from residential to NPP is within 50 km - No association between the proximity of maternal residential homes to NPP and LBW for group: 40-50 km (95% CI = 0.81, 1.03); 30-40 km (95% CI = 0.84, 1.13); 20-30 km (95% CI = 0.79, 1.15); 10-20 km (95% CI = 0.70, 1.04); 0-10 km (95% CI = 0.59, 1.61)
[3]	Mangones et al. (2013); US	Congenital anomalies, prematurity, and low birth weight rates with nuclear power plant proximity	Cross-sectional study; 9 years of medical records (1992 – 2001)	NPP; N/A	Congenital anomalies, low birth weight and premature birth; 328,124	- Distance from residential to NPP is within a 32.19 km radius - No association between the proximity of maternal residential homes to NPP and birth defects (95% CI = 0.366-0.425)
[4]	Queisser-luft et al. (2011); Germany	Birth defects in the vicinity of nuclear power plants in Germany	Cohort study; 1-year of medical records (2007 – 2008)	NPP; N/A	Birth defects; 5,273	- Distance from residential to NPP is within 10 km - No association between the proximity of maternal residential homes (during the conception phase) to the NPP and birth defects (p = 0.82)
[5]	Wang et al. (2010); Taiwan	Pregnancy outcome of women in the vicinity of nuclear power plants in Taiwan	Cross-sectional study; 3 years of medical records (2001 – 2004)	NPP; < 0.2 µSv/h (1.8 mSv/year)	Stillbirth, premature birth, low birth weight, and congenital anomalies; 5,679	- Distance from residency to the NPP is within 14.23 km - Non-significant associations between distance and stillbirth (95% CI = 0.56-2.56), premature birth (95% CI =0.95-1.53), LBW (95% CI =0.79-1.37), and birth defects (95% CI =0.85-2.93)
[6]	Slama et al. (2008); France	Reproductive life events in the population living in the vicinity of a nuclear waste reprocessing plant	Cross-sectional study; 15 years of medical records (1985 – 2000)	NPP; N/A	Miscarriage and low birth weight; 1,183	- No increased risk of miscarriage (p = 0.70) and LBW (p = 0.80) in the population living in the vicinity of the NPP

[7]	Dummer et al. (1998); UK	Stillbirth rates around the nuclear installation at Sellafield, Northwest England: 1950-1989 (39 years)	Cohort study; 39 years of medical records (1950 – 1989)	NPP; N/A	Stillbirths; 260,100	- The outcome was observed for those who resided within 25 km of the nuclear plant - Distance from NPP did not significantly influence stillbirth (p = 0.30)
[8]	Shield et al. (1992); US	Navajo birth outcomes in the Shiprock uranium mining area	Case-control study; 18 years of medical records (1964 – 1981)	UPP; 1.7 – 5.2 mSv/year	Adverse pregnancy outcomes were grouped into 5 categories (in total 320 kinds of defective congenital conditions); 13,329	- Distance from residency to UPP is within 0.805 km - A statistically significant association was recorded between mothers living near UPP (mines) and the outcome of Group 2** (OR 2.71, p = 0.03). The associations of the observed outcomes were weak and must be interpreted with caution. ***Hip dysplasia and dislocation, cerebral palsy, mental retardation, stillbirths, infection and neoplasm.*

*N/A: No available data; NPP: Nuclear power plants; UPP: Uranium processing plant

Table 2: Checklist for Quality Assessment [Adapted from Crowe (2013)]

No.	Item	Selected articles							
		[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]
1.	Preliminaries - Title (aims and design) - Abstract (key information, balanced, informative) - Text (sufficient detail, clear writing/ table/ diagram/ figure)	5	5	5	5	5	5	5	4
2.	Introduction - Background - Objective	5	5	5	5	5	5	4	4
3.	Design	3	4	4	4	4	5	4	4
4.	Sampling	2	3	3	3	3	5	3	3
5.	Data collection	2	3	2	3	3	5	4	3
6.	Ethical matters	0	3	5	5	3	3	3	3
7.	Results	3	4	3	4	5	5	3	4
8.	Discussion	2	5	5	5	5	3	4	3
9.	Total (%)	55	80	80	85	83	90	75	70

DISCUSSIONS

In this review, we have systematically synthesized the existing evidence on the effects of maternal exposure to ionizing radiation (IR) and its effect on pregnancy outcomes. Our findings highlight the limited number of published articles that examine the studied relationship. The main adverse pregnancy outcomes observed by the selected studies were birth defects, premature birth, miscarriage and LBW. However, based on the findings, only one study found a significant association between the mother's residence near the UPP and the effect on birth defects (Shield et. Al., 1992). Other studies did not find any significant relationship of the observed outcomes, hence the definite conclusive to associate the exposure and the outcome was not able to be obtained.

Maternal exposure to ionizing radiation (IR) from nuclear power plants or mines

The stages of pregnancy (trimester window) and the absorbed radiation dose by the human body are

associated with the severity of radiation effects towards pregnancy outcomes (Shaw et al., 2011). The majority of articles did not measure the individual radiation exposure level, hence we were not able to determine whether the radiation exposure in that area exceeded the dose limit or not. Only minimum information was obtained from Wang et al. (2010) and Shields et al. (1992), in which the IR level was recorded at 1.8 and 1.7 – 5.2 mSv per year, respectively. As reported in BEIR VII, radiation exposure below 100 mSv/year is considered low exposure levels (National Research Council, 2006). In terms of absorbed radiation dose, the radiation level of 50 mSv is the dose limit for the general population where these levels may cause stochastic effects on humans including malformation and mental retardation in the fetus (Streffer et al., 2003). Also, in human studies, it is hard to distinctly observe the effect of radiation on the embryo or fetus with a dose range of less than 100 mSv (Kusama & Ota, 2002).

The results of the selected articles showed that the effects of radiation on pregnancy outcomes are weak and almost have no evidence. Even Shield et al. (1992) have recorded a statistically significant association between mothers living near UPP and the outcome of Group 2 (hip dysplasia and dislocation, cerebral palsy, mental retardation, stillbirths, infection and neoplasm), but the associations of the observed outcomes were weak (OR 2.71, P=0.03, n=113 cases) and must be interpreted with caution due to small study population. The effects of radiation usually are based on long-term exposure, and maybe the exposure during the gestational duration (40 weeks or 280 days) is not sufficient to observe the health effects.

The proximity of maternal residences to nuclear power plants and the risk of adverse pregnancy outcomes

Based on the selected articles, different methods were applied to determine the IR exposure from maternal residency to NPP or UPP (mines). The selected articles have measured the distance between both locations by using a variety of distance thresholds. For example, 32.19 km of the radius was divided into four zones of 8.05 km increments (Mangones et al., 2013), 25 km of the radius was divided by 5 km increments (Dummer et al., 1998) and 50 km was further divided into five equal interval groups using thresholds 10, 20, 30, and 40 km (Gong et al., 2016). However, if the distance thresholds are too small, there would be a very small sample size in that particular area, hence reducing the power of the study (Gong et al., 2016). Therefore, it is recommended that distance thresholds between the areas be defined on an appropriate and consistent scale relative to other thresholds to ensure that each proximity group has a sufficient sample size for the statistical analysis (Gong et al., 2016).

Among all the selected studies, Shield et al. (1992) utilized the shortest distance (<1 km) between the UPP and maternal residency, compared to other studies that used a distance ranging between 10 to 50 km. This closer proximity may explain the significant findings in their study; however, many factors must also need to be considered.

Based on the major findings in this review, it is evident that the distance (within 50 km or less from the source of apportionment) did not result in adverse pregnancy outcomes. A possible explanation for this result may be due to the reduction of radionuclide deposition near the point of source, thereby lowering the exposure radiation level in the nearest areas. In industrial settings, the use of a high chimney stack could contribute to this reduction, as the stack releases the industrial pollutants on an upward trajectory, causing them to disperse away from the source (Lawson & Waller, 1996).

The adverse pregnancy outcomes that have been discussed in the selected articles are subject to some limitations including lower birth rate in the study area and poor access to health care services and facilities. As a result, these contributed to the abortions or underreporting of adverse pregnancy outcomes in that particular location (Mangones et al., 2013). A study conducted by Dummer et al. (2008) found no statistical evidence for an increased risk of stillbirths with closer proximity to NPP. The data of this study showed the increased risk of stillbirths recorded in two areas located within 10-15 km from NPP in the northwest sea and 15-20 km from NPP in the northeast sea. However, the increased risk of stillbirth in both stated locations was not due to the proximity of residency to the NPP, but it is related to the high population in that study area that may cause high chances of getting adverse pregnancy outcomes.

As for the recommendation for future studies, it is suggested that future research also include other contributing factors that can increase the risk of adverse pregnancy outcomes such as maternal factors (smoking, alcohol consumption, nutritional and social status), hereditary factors and external environmental factors (Wang et al., 2009). More future research is needed to find evidence to support the association between IR exposure from NPP or mining activity and adverse pregnancy outcomes because of the severe effect of NPP accidents and widespread radiation exposure in the

population, even though the selected articles did not manage to provide evidence for such association.

CONCLUSION

The finding of this study suggests that maternal exposure to IR from nuclear power plants NPP or mines is unlikely to be associated with adverse pregnancy outcomes. The proximity of maternal residential homes to the industrial area, specifically NPP, was not correlated to adverse pregnancy outcomes such as LBW, stillbirth, spontaneous abortion or birth defects. Overall, the primary strength of this review lies in the large sample sizes across all the selected studies, which contribute to a high level of statistical power. However, this review is limited by a relatively small number of publications addressing this association. Additionally, as a retrospective study, individual radiation exposure levels could not be determined in all selected studies. None of the studies measured the real-time radiation exposure levels, making it impossible to ascertain the actual radiation doses exposed by the populations. Hence, it is recommended that future research emphasize individual exposure levels on specific trimester windows, as well as investigate the biological mechanisms underlying the relationship between radiation exposure during pregnancy and adverse pregnancy outcomes.

ACKNOWLEDGEMENTS

This research was supported by the IIUM-UMP-UITM Sustainable Research Collaboration Grant 2020 (Grant ID: SRCG20-040-0040). The authors also would like to extend their gratitude to Dar al-Hikmah Library, IIUM Kuantan, for providing access to databases which were essential to the completion of this study. The authors declare no conflict of interest.

REFERENCES

Crowe, M., Sheppard, L., & Campbell, A. (2011). Comparison of the effects of using the Crowe Critical Appraisal Tool versus informal appraisal in assessing health research: a randomised trial. *International Journal of Evidence-Based Healthcare*, *9*(4), 444–449. https://doi.org/10.1111/j.1744-1609.2011.00237.x

Dummer, T. J., Dickinson, H. O., Pearce, M. S., Charlton, M. E., Smith, J., Salotti, J., & Parker, L. (1998). Stillbirth rates around the nuclear installation at Sellafield, North West England: 1950-1989. *International journal of epidemiology*, *27*(1), 74–82. https://doi.org/10.1093/ije/27.1.74

Gong, X., Benjamin Zhan, F., & Lin, Y. (2017). Maternal residential proximity to nuclear facilities and low birth weight in offspring in Texas. *Radiation and environmental biophysics*, *56*(1), 111–120. https://doi.org/10.1007/s00411-016-0673-2

ICRP, 2007. The 2007 Recommendations of the International Commission on Radiological Protection. ICRP Publication 103. Ann. ICRP 37 (2-4).

Jírová, J., Michalová, Z., Beránek, L., Kotrbová, K., & Zölzer, F. (2020). Incidence of spontaneous abortions and congenital anomalies in the vicinity of a uranium processing plant. *Central European journal of public health*, *28*(1), 44–47. https://doi.org/10.21101/cejph.a4977

Kusama, T., & Ota, K. (2002). Radiological protection for diagnostic examination of pregnant women. *Congenital Anomalies*, *42*(1), 10–14. https://doi.org/10.1111/j.1741-4520.2002.tb00848.x

Lawson, A. B., Waller, L. A. A review of point pattern methods for spatial modelling of events around sources of pollution. *Environmelrics* 1996; 7:471-87 [cited in Dummer et al. (1998)].

Mangones, T., Visintainer, P., & Brumberg, H. L. (2013). Congenital anomalies, prematurity, and low birth weight rates in relation to nuclear power plant proximity1). *Journal of Perinatal Medicine*, *41*(4). https://doi.org/10.1515/jpm-2012-0061

Moher, D., Liberati, A., Tetzlaff, J., & Altman, D. G. (2009). Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. *PLoS Medicine*, *6*(7), e1000097. https://doi.org/10.1371/journal.pmed.1000097

National Research Council. (2006). *Health risks from exposure to low levels of ionizing radiation: BEIR VII Phase 2.* The National Academies Press. https://doi.org/10.17226/11340

Queisser-Luft, A., Wiesel, A., Stolz, G., Mergenthaler, A., Kaiser, M., Schlaefer, K., Wahrendorf, J., Blettner, M., & Spix, C. (2011). Birth defects in the vicinity of nuclear power plants in Germany. *Radiation and environmental biophysics*, *50*(2), 313–323. https://doi.org/10.1007/s00411-010-0349-2

Shaw, P., Duncan, A., Vouyouka, A., & Ozsvath, K. (2011). Radiation exposure and pregnancy. *Journal of Vascular Surgery* (Vol. 53, Issue 1 SUPPL., pp. 28S-

34S). Mosby Inc. https://doi.org/10.1016/j.jvs.2010.05.140

Shields, L. M., Wiese, W. H., Skipper, B. J., Charley, B., & Benally, L. (1992). Navajo birth outcomes in the Shiprock uranium mining area. *Health physics*, *63*(5), 542–551. https://doi.org/10.1097/00004032-199211000-00005

Slama, R., Boutou, O., Ducot, B., & Spira, A. (2008). Reproductive life events in the population living in the vicinity of a nuclear waste reprocessing plant. *Journal of epidemiology and community health*, *62*(6), 513–521. https://doi.org/10.1136/jech.2007.061069

Streffer, C., Shore, R., Konermann, G., Meadows, A., Uma Devi, P., Preston Withers, J., Holm, L. E., Stather, J., Mabuchi, K., & H R (2003). Biological effects after prenatal irradiation (embryo and fetus). A report of the International Commission on Radiological Protection. *Annals of the ICRP*, *33*(1-2), 5–206.

Tadese, M., Dagne, K., Wubetu, A. D., Abeway, S., Bekele, A., Misganaw Kebede, W., & Baye Mulu, G. (2022). Assessment of the adverse pregnancy outcomes and its associated factors among deliveries at Debre Berhan Comprehensive Specialized Hospital, Northeast Ethiopia. *PloS one*, *17*(7), e0271287. https://doi.org/10.1371/journal.pone.0271287

Tsou, M.-W., Liu, J.-T., Hammitt, J. K., Lu, C.-H., & Kao, S.-Y. Z. (2019). The effect of prenatal exposure to radiation on birth outcomes: exploiting a natural experiment in Taiwan. *The Japanese Economic Review*, *71*(3), 379–403. https://doi.org/10.1007/s42973-019-00016-9

United States Nuclear Regulatory Commission (USNRC, 2020). *Radiation Basics*. https://www.nrc.gov/about-nrc/radiation/health-effects/radiation-basics.html

Wang, S. l., Lee, L. T., Zou, M. L., Fan, C. W., & Yaung, C. L. (2009). Pregnancy outcome of women in the vicinity of nuclear power plants in Taiwan. *Radiation and Environmental Biophysics*, *49*(1), 57–65. https://doi.org/10.1007/s00411-009-0246-8

World Nuclear Association. (n.d.). *What is Background Radiation*. http://www.world-nuclear.org/uploadedFiles/org/Features/Radiation/4_Background_Radiation%281%29.pdf

International Labour Organization (ILO, 2024). https://www.ilo.org/topics/safety-and-health-work/physical-hazards-and-risks#:~:text=Radiation%20hazards%20encompass%20exposure%20to,the%20radiation%20from%20radioactive%20materials.

Streffer C, Shore R, Konermann G, Meadows A, Uma Devi P, Preston Withers J, et al. Biological effects after prenatal irradiation (embryo and fetus). A report of the International Commission on Radiological Protection. Ann ICRP. 2003;33(1-2):5-206.