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Radioactive releases from the nuclear power sector and implications for child health

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Radioactive releases from the nuclear power sector and implications for child health

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Abstract

Radioactivity is released routinely at every stage of nuclear power generation, adversely affecting children and pregnant women the most. From uranium mining and milling, to fuel manufacture, electricity generation and radioactive waste management, children in frontline and Indigenous communities are often disproportionately harmed the most due to lack of resources as well as racial and class discrimination. The reasons for the greater susceptibility of women and children to harm due to radiation exposure is not fully understood, but regulatory practices, particularly in the establishment of protective exposure standards, have failed to take this difference into account. Anecdotal evidence within communities around nuclear facilities, and particularly around uranium mines, suggests a strong correlation between increases in birth defects, miscarriages and childhood cancers and radiation exposure, yet academic studies tend to ascribe causality to other factors related to diet and lifestyle and dismiss these health indicators as statistically insignificant. In the case of a major release of radiation due to a serious nuclear accident, children are again on the frontlines, with a noted susceptibility to thyroid cancer, which has been found in significant numbers among children exposed both by the 1986 Chernobyl nuclear accident in Ukraine and the 2011 Fukushima Daiichi nuclear disaster in Japan. The response among authorities in Japan is to blame this on increased testing, or to reduce testing. More independent studies are needed focused on children, especially those in vulnerable frontline and Indigenous communities. In conducting such studies, greater sensitivity must be applied to culturally significant traditions and habits in these communities when assessing health impacts.

Key Messages

1. Exposure to radioactivity released at every stage of nuclear power production, disproportionately impacts the health of childhood, pregnancy, women and minorities.

2. A nuclear accident releasing large amounts of radiation harms those immediately affected as well as future generations exposed to long-term low radiation doses.

3. Radiation exposure studies in the nuclear sector often overlook the sensitivities of women, children and minorities or apply inappropriate models to assess the impacts.

4. Those studies that focus on the more susceptible populations have recorded significant disproportionate harm to health compared to others in the population.

5. Authorities frequently endeavour to suppress or dismiss data that show a correlation between radiation exposure from nuclear emissions and negative health outcomes.

Radioactivity is released at every stage of nuclear power production, from uranium mining to electricity generation to radioactive waste production.

Children, as well as their mothers, and especially pregnant women, living near nuclear production facilities, are known to be at disproportionately higher risk of harm from exposure to these releases. Children in poorer, often Non-White and Indigenous communities, are even more vulnerable, due to socio-economic factors and discrimination.

However, in a review of the studies, we find a notable lack of in-depth, independent research looking specifically at children, as well as the wider population in Indigenous or minority communities, those often on the frontlines of radiation exposure. Uncertainties caused by this lack of study are used by officials to underprotect those most at risk.

We also find a marked contrast between the conclusions of some of the studies and the anecdotal evidence on the ground.

Most of the primary research that *has* focused on the susceptibilities of women and children has consistently demonstrated disproportionate impacts, even at lower doses, including increases in childhood cancers, particularly leukaemia and central nervous system cancers, impaired neural development, lower IQ, birth defects, respiratory difficulties, cardiovascular dysfunction and perinatal mortality. Rapid cell division is among the development processes thought to account for some of this susceptibility.

However, many studies are unable to link these adverse outcomes to radioactivity because they tend to suffer from several faulty assumptions. These include that:

1) Doses were too low — a beginning assumption ensuring poor hypothesis formation and study design[1]— absolving radioactivity, while also leading to an inability to find an alternate associated disease agent;

2) Small negative findings matter. In fact, what matters are positive findings or very large negative findings[2];

3) "Statistical non-significance" means a *lack* of association between radiation exposure and disease — a usage scientists in various disciplines now call "ludicrous."[3]

As such, studies mentioned here will be reviewed through the lens of accounting for these faulty assumptions.

Children are underprotected by the current regulatory standards, which are based on "allowable" or "permissible" doses, (rather than "safe") for a 20-30 year old white male, or "Standard Man". Authorities were clearly aware of the higher susceptibility of children in early research, when a "Standard Child" radiation damage model – subsequently abandoned – was briefly considered in 1960. At that time, a "permissible dose" was more aptly recognized as an "acceptable injury" limit, but that language was quickly sanitised.

Figure 1. Selected radioisotopes: where they travel and primarily collect in the body [4]

Uranium mining and racial discrimination

Uranium mining contributes significantly to the wide and deadly dispersal of radioactive waste streams into the air, water and soil. Uranium mining also leaves behind a massive debris field of discarded radioactive residues, rocks and heavy metals, known as tailings.

In the United States, Native American communities have constituted the majority of the uranium mining workforce. In the American Southwest, Navajo Nation community members demonstrate an increased and unique sensitivity to uranium mine waste — a phenomenon that is not yet fully

[1] Wing S, Richardson DB, Hoffmann W. Cancer risks near nuclear facilities: the importance of research design and explicit study hypotheses. *Environ Health Perspect*. 2011;119(4):417-421. doi:10.1289/ehp.1002853

[2] Ian Fairlie I, Sumner D. The Other Report on Chernobyl: An Independent Scientific Evaluation of the Health-Related Effects of the Chernobyl Nuclear Disaster. Vienna: Weiner Umweltanhaltschaft. 2016:98-100.

[3] Amrhein V, Greenland S, McShane B. Scientists rise up against statistical significance.

[4] We would like to recognize and thank the Radiation Monitoring Project for this image. RMP hosted workshops on understanding and monitoring radioactive contamination in the environment by purchasing and distributing radiation detectors to contaminated and frontline communities, focusing on Native Americans. RMP is a collaboration between Diné No Nukes, Nuclear Energy Information Service & Sloths Against Nuclear State.

explored or explained, even by expected risk factors,[5,6] although this community is living with a 150-year health legacy of potential exposure to radioactive and metal mine waste. Navajo Nation community members have experienced increases in a number of diseases and lingering internal contamination from uranium mine waste among neonates and children [7],[8],[9],[10].

An examination of Navajo babies born between 1964 and 1981 showed that congenital anomalies, developmental disorders, and other adverse birth outcomes were associated with the mother living near uranium mines and wastes. The results of this study, published in 1992, were only followed up beginning in 2010 with the establishment of the Navajo Birth Cohort study, a community-based and -driven initiative that examines the impact of chronic exposure to mine wastes on birth outcomes.

Historic and recent official research has, on the whole, been systemically racist by failing to account for culturally-specific exposure scenarios to Navajo. These include frequent contact with contaminated lands, waters and, in some cases, a nearly 100% reliance on locally grown and sourced foods[11,12], as well as failure to consider doses to Navajo Nation community members from the Trinity explosion—the first detonation of an atomic device[13].

In Jadugoda, India, where six uranium mines operate, the first opening in 1957, those affected are Indigenous peoples from the Santhal, Munda and Ho tribes. A local organisation, Jharkhandi Organisation Against Radiation, has been monitoring community health for decades, uncovering an abnormally high rate of birth defects.

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[5] Lewis J, Hoover J, MacKenzie D. Mining and Environmental Health Disparities in Native American Communities. *Curr Environ Health Rep*. 2017;4(2):130-141. doi:10.1007/s40572-017-0140-5

[6] DeLemos J, Rock T, Brugge D, Slagowski N, Manning T, Lewis J. Lessons from the Navajo: assistance with environmental data collection ensures cultural humility and data relevance. *Prog Community Health Partnersh*. 2007;1(4):321-326. doi:10.1353/cpr.2007.0039

[7] Erdei E, Shuey C, Pacheco B, Cajero M, Lewis J, Rubin RL. Elevated autoimmunity in residents living near abandoned uranium mine sites on the Navajo Nation. *J Autoimmun*. 2019;99:15-23. doi:10.1016/j.jaut.2019.01.006

[8] Cooper KL, Dashner EJ, Tsosie R, Cho YM, Lewis J, Hudson LG. Inhibition of poly(ADP-ribose)polymerase-1 and DNA repair by uranium. *Toxicol Appl Pharmacol*. 2016;291:13-20. doi:10.1016/j.taap.2015.11.017

[9] Harmon ME, Lewis J, Miller C, et al. Residential proximity to abandoned uranium mines and serum inflammatory potential in chronically exposed Navajo communities. *J Expo Sci Environ Epidemiol*. 2017;27(4):365-371. doi:10.1038/jes.2016.79

[10] Lewis J, Hoover J, MacKenzie D. Mining and Environmental Health Disparities in Native American Communities. *Curr Environ Health Rep*. 2017;4(2):130-141. doi:10.1007/s40572-017-0140-5

[11] Lewis J, Hoover J, MacKenzie D. Mining and Environmental Health Disparities in Native American Communities. *Curr Environ Health Rep*. 2017;4(2):130-141. doi:10.1007/s40572-017-0140-5

[12] DeLemos J, Rock T, Brugge D, Slagowski N, Manning T, Lewis J. Lessons from the Navajo: assistance with environmental data collection ensures cultural humility and data relevance. *Prog Community Health Partnersh*. 2007;1(4):321-326. doi:10.1353/cpr.2007.0039

[13] Cahoon EK, Zhang R, Simon SL, Bouville A, Pfeiffer RM. Projected Cancer Risks to Residents of New Mexico from Exposure to Trinity Radioactive Fallout [published correction appears in Health Phys. 2021 Jan;120(1):97]. *Health Phys*. 2020;119(4):478-493. doi:10.1097/HP.0000000000001333

An independent study[14] of the Jadugoda community conducted in 2007 by Indian Doctors for Peace and Development, concluded that "The finding of the study confirms the hypotheses that the health of indigenous people around uranium mining is more vulnerable to certain health problems".

Included in their findings were that babies born to mothers living near uranium mining operations, "suffered a significant increase in congenital deformities. While 4.49% mothers living in the study villages reported that children with congenital deformities were born to them, only 2.49% mothers in reference villages fell under this category".

Figure 2. Congenital deformities among babies from mothers who lived near the Jadugoda uranium mining operations.

However, other studies contradict these conclusions. A 2013 study[15] by A C Patra et al., concluded that "the water is safe for drinking". And, perhaps unsurprisingly, a study[16] by scientists from India's Bhabha Atomic Research Centre, came to a similar conclusion. However, these studies are deficient in many ways, limiting their research to dose reconstruction rather than health outcomes and failing to consider inhalation or ingestion of radionuclides, other than from drinking water. The obvious association with the Atomic Research Centre further compromises credibility.

People living in the town of Arlit in Niger, and those working in the huge French-owned uranium mine nearby, are exposed on a daily basis to levels of radioactivity higher than those found in the Chernobyl exclusion zone. Independent studies in Arlit[17], beginning in 2003, found radioactively contaminated metals discarded from the mine routinely used in households, where children were exposed.

An independent study commissioned by the European Parliament and published in 2010, looked at health and environmental legacy conditions around uranium mines in both Gabon and Niger and found, in the case of Niger, that "waste dumps and related processing facilities are posing a severe environmental and health hazard to the local population".[18] It further noted that "There is evidence of radioactive contamination of local water supplies, and contaminated dust,"

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[14] Rahman S. et al. "Study on health status of indigenous people around Jadugoda uranium mines in India." Indian Doctors for Peace and Development, 2010.

[15] Patra AC, Mohapatra S, Sahoo SK, Lenka P, Dubey JS, Tripathi RM, Puranik VD. Age-dependent dose and health risk due to intake of uranium in drinking water from Jaduguda, India. Radiat Prot Dosimetry. 2013 Jul;155(2):210-6. doi: 10.1093/rpd/ncs328. Epub 2013 Mar 22. PMID: 23525912.

[16] N.K. Sethy et al, Assessment of Natural Uranium in the Ground Water around Jaduguda Uranium Mining Complex, India,. Journal of Environmental Protection. August 27, 2011.

[17] B. Chareyron, CRIIRAD, AREVA : Du discours à la réalité / L'exemple des mines d'uranium du Niger, January 2008, 5.24.0.00/08 (NIGER)

[18] Veit, Sebastian, Srebotnjak, Tanja, Potential use of radioactively contaminated materials in the construction of houses from open pit uranium mine materials in Gabon and Niger, European Parliament, November 19, 2010.

and that “Contaminated construction materials have been sold on local markets and were found in dwellings and in the towns”.[19]

In Australia, uranium contaminates drinking water around uranium mine sites at rates far higher than recommended. Aboriginal communities, most likely to inhabit land around these facilities, suffer from increases in cancers and stillbirths.

A 2019 Australian government study[20] found increases in low birth weight, foetal death and cancers, but a “lack of evidence” that alcohol and tobacco use, and a high-fat diet, could explain the full increase in diseases. Radiation was eliminated because the doses were considered too low, despite its known connection to low birth weight and cancers. This conclusion left the community with unexplained disease increases, a pattern seen all too often in radiation health studies.

In her analysis, Rosalie Schultz states that “We owe it to Aboriginal people living near mines to understand and overcome what’s making them sick”,[21] and further points out that “Development of the Ranger mine entailed nullification of veto rights, disempowering Aboriginal communities and threatening their livelihoods. With mining came royalty money, expensive commodities, money-hunger and alcohol”.

These examples serve to highlight the tension between the often strong anecdotal evidence on the ground and the common failure to attribute the causal factor to the most likely “suspect”, given the health outcomes are often strongly associated with exposure to radioactivity.

Routine radioactive releases from nuclear power plants

Nuclear power plants routinely release radioactivity as part of daily operation. In 2008, a landmark case-control study was published in Germany[22], known as the KiKK study.

It revealed an unsettling 1.6-fold increase in all cancers and a 2.2-fold increase in leukemias among children under five years old living within 5km of operating nuclear power plants.

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[19] Ibid.

[20] Guthridge S et al., Gunbalanya-Kakadu disease cluster investigation. Final report, Northern Territory Government, EDOC2020/34649, September 2019.

[21] Schultz R. Investigating the health impacts of the Ranger uranium mine on Aboriginal people. Med J Aust. 2021 Aug 16;215(4):157-159.e1. doi: 10.5694/mja2.51198. Epub 2021 Aug 1. PMID: 34333775.

[22] Kaatsch P, Spix C, Schulze-Rath R, Schmiedel S, Blettner M. Leukaemia in young children living in the vicinity of German nuclear power plants. Int J Cancer. 2008 Feb 15;122(4):721-6. doi: 10.1002/ijc.23330. PMID: 18067131.

In general, the incidences were higher the closer the children lived to the nuclear plant. The KiKK findings were backed up by other studies,[23] and a meta-analysis.[24]

However, the authors concluded that their findings were "unexplainable" because the doses were assumed to be too low to cause cancer. But UK radiation researcher, Dr. Ian Fairlie, hypothesises that sudden large spikes in radiation releases during reactor refuelling resulted in higher doses. These could account for higher rates of leukaemia among children.[25]

Fairlie further posits "the observed high rates of infant leukemias may be a teratogenic effect from radionuclides incorporated during pregnancy."[26]

Other studies associate childhood cancers with doses that are much lower than these spikes, but delivered continuously. Taken together, these studies indicate that pregnancy development possesses unique sensitivities to radiation exposure.

Table 1. Pooled analysis of leukemias in children under 5 years of age within 5 km of nuclear reactors in Europe. Used with permission of Ian Fairlie.

Catastrophic radioactive waste releases
Catastrophic releases of radioactivity from the 1979 Three Mile Island (TMI) accident in the U.S., the 1986 Chernobyl disaster in Ukraine and the 2011 Fukushima, Japan nuclear disaster, disproportionately harmed children's health.

During the TMI crisis, there were 24 spontaneous abortions or stillbirths among pregnant women who were living within five miles of the nuclear facility and in their first four months of pregnancy. The expected number should be closer to twelve. The researchers of a study examining this, posit this may be due stress, a possibility that they themselves appear to discount in this same study.[27]

Radiation from the TMI catastrophe was also associated with childhood leukaemia. Interestingly, an association with radiation exposure and all childhood cancers was also present

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[23] Fairlie I, Körblein A. Review of epidemiology studies of childhood leukaemia near nuclear facilities: commentary on Laurier et al. *Radiat Prot Dosimetry*. 2010;138(2):194-197. doi:10.1093/rpd/ncp246
[24] Baker PJ, Hoel D: Meta-analysis of standardized incidence and mortality rates of childhood leukemias in proximity to nuclear facilities. Eur J Cancer Care. 2007, 16: 355-363. 10.1111/j.1365-2354.2007.00679.
[25] Fairlie I. A hypothesis to explain childhood cancers near nuclear power plants, Journal of Environmental Radioactivity 133 (July 2014): 10-17.
[26] Fairlie I. Commentary: childhood cancer near nuclear power stations. Environ Health. 2009 Sep 23;8:43. doi: 10.1186/1476-069X-8-43. PMID: 19775438; PMCID: PMC2757021.
[27] Goldhaber MK, Staub SL, Tokuhata GK. Spontaneous abortions after the Three Mile Island nuclear accident: a life table analysis. *Am J Public Health*. 1983;73(7):752-759. doi:10.2105/ajph.73.7.752

before the catastrophe, indicating routine releases were to blame – something the study recognizes as "compatible with increases reported near some other nuclear installations…" [28]

Outcomes in the Former Soviet States (FSS) from initial exposure to Chernobyl radioactive fallout include thyroid cancers (predominantly among those exposed during childhood) and significant increases in leukaemia among children who were in utero or who were under six years of age at the time of the Chernobyl catastrophe[29]. Also found were increases in radiation-induced organic mental disorders.[30]

Among those continuing to live in Chernobyl-contaminated areas in the FSS, we see increases in cardiovascular disorders[31],[32] decreased lung function [33],[34] defects of the lens of the eye [35], and significantly increased rates of conjoined twins, teratomas, neural tube defects, microcephaly, and microphthalmia.[36] Further, research indicates significantly higher birth defects—some de novo— in the Chernobyl-contaminated Bryansk region. Projections indicate that certain birth defects will increase in the next few years.[37]

The Chernobyl disaster produced a phenomenon known as "Chernobyl heart", where children were born with multiple heart defects – now being observed among children exposed as a result of the Fukushima catastrophe.[38] Some of these impacts occur at low, chronic doses.

Outside of the FSS, children born in regions of Sweden with higher Chernobyl fallout performed worse in secondary school – particularly in maths – and had more behavioural problems.[39]

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[28] Hatch MC, Beyea J, Nieves JW, Susser M. Cancer near the Three Mile Island nuclear plant: radiation emissions. *Am J Epidemiol*. 1990;132(3):397-417. doi:10.1093/oxfordjournals.aje.a115673

[29] International Consortium for Research on the Health Effects of Radiation Writing Committee and Study Team, Davis S, Day RW, et al. Childhood leukaemia in Belarus, Russia, and Ukraine following the Chernobyl power station accident: results from an international collaborative population-based case-control study. *Int J Epidemiol*. 2006;35(2):386-396. doi:10.1093/ije/dyi220

[30] Nyagu AI, Loganovsky KN, Loganovskaja TK, Repin VS, Nechaev SY. Intelligence and brain damage in children acutely irradiated in utero as a result of the Chernobyl accident. KURRI KR. 2002;79:202-30.

[31] Bandazhevsky YI, Lelevich VV. Clinical and experimental aspects of the effect of incorporated radionuclides upon the organism. Belarus (UDC 616–092: 612.014. 481/. 482) Gomel. 1995:128.

[32] Bandazhevskaya GS. The State of Cardiac Activity among Children Living in Areas Contaminated with Radionuclides/Medical Aspects of Radioactive Impact on the Population Living in the Contaminated Territories after the Chernobyl Accident: Proceedings of the International Scientific Symposium. InProceedings of the International Scientific Symposium 1994.

[33] Svendsen ER, Kolpakov IE, Stepanova YI, et al. 137Cesium exposure and spirometry measures in Ukrainian children affected by the Chernobyl nuclear incident. *Environ Health Perspect*. 2010;118(5):720-725. doi:10.1289/ehp.0901412

[34] Svendsen ER, Kolpakov IE, Karmaus WJ, et al. Reduced lung function in children associated with cesium 137 body burden. *Ann Am Thorac Soc*. 2015;12(7):1050-1057. doi:10.1513/AnnalsATS.201409-432OC

[35] Day R, Gorin MB, Eller AW. Prevalence of lens changes in Ukrainian children residing around Chernobyl. *Health Phys*. 1995;68(5):632-642. doi:10.1097/00004032-199505000-00002

[36] Wertelecki W, Yevtushok L, Zymak-Zakutnia N, et al. Blastopathies and microcephaly in a Chornobyl impacted region of Ukraine. *Congenit Anom (Kyoto)*. 2014;54(3):125-149. doi:10.1111/cga.12051

Similarly, in Norway, in utero exposure to Chernobyl radiation is associated with significantly lower verbal IQ, verbal working memory, and executive functioning.[40],[41]

In Central Europe, studies observed a statistically significant increase in childhood leukemias.[42] Perinatal mortality increased in European and FSS countries after the Chernobyl catastrophe,[43] and increases in trisomy 21 were found in Berlin and Belarus in 1987/1988. The cases coincided with exposure to Chernobyl fallout.[44]

Thyroid cancers among those exposed to Fukushima radiation as children have increased 20 times the expected rate, with about 80% metastasizing[45] – meaning surgery was medically indicated and screening necessary.

Despite this, SHAMISEN, a project funded by the European Commission, has recommended against systematic thyroid screening after nuclear catastrophes, claiming over-diagnosis and psychosocial impact can result.[46] This seems to be a disturbing trend following Fukushima – to avoid looking for health impacts from radiation by suggesting that these medical examinations are psychologically scarring.[47]

But Toshihide Tsuda, an epidemiologist in Japan, found that “[a]n excess of thyroid cancer has been detected and is unlikely to be explained by a screening surge.” [48] However, because of an overall lack of focus on public health and epidemiological training in Japan, the ability to officially

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[37] Korsakov AV, Geger EV, Lagerev DG, Pugach LI, Mousseau TA. *De novo* congenital malformation frequencies in children from the Bryansk region following the Chernobyl disaster (2000-2017). *Heliyon*. 2020;6(8):e04616. Published 2020 Aug 17. doi:10.1016/j.heliyon.2020.e04616

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[39] Almond D, Edlund L, Palme M. Chernobyl's subclinical legacy: prenatal exposure to radioactive fallout and school outcomes in Sweden. The Quarterly journal of economics. 2009 Nov 1;124(4):1729-72.

[40] Heiervang KS, Mednick S, Sundet K, Rund BR. Effect of low dose ionizing radiation exposure in utero on cognitive function in adolescence. *Scand J Psychol*. 2010;51(3):210-215. doi:10.1111/j.1467-9450.2010.00814.x

[41] Heiervang KS, Mednick S, Sundet K, Rund BR. The Chernobyl accident and cognitive functioning: a study of Norwegian adolescents exposed in utero. *Dev Neuropsychol*. 2010;35(6):643-655. doi:10.1080/87565641.2010.508550

[42] Hoffmann W. Has fallout from the Chernobyl accident caused childhood leukaemia in Europe? A commentary on the epidemiologic evidence. *Eur J Public Health*. 2002;12(1):72-76. doi:10.1093/eurpub/12.1.72

[43] Korblein A. Strontium fallout from Chernobyl and perinatal mortality in Ukraine and Belarus. *Radiats Biol Radioecol*. 2003;43(2):197-202.

[44] Sperling K, Neitzel H, Scherb H. Evidence for an increase in trisomy 21 (Down syndrome) in Europe after the Chernobyl reactor accident. *Genet Epidemiol*. 2012;36(1):48-55. doi:10.1002/gepi.20662

[45] Hiranuma Y. Fukushima Thyroid Examination Fact Sheet: September 2017. dent. 2012;11:11.

[46] SHAMISEN Consortium. In collaboration with EU OPERRA and IS Global. Recommendations and Procedures for Preparedness and Health Surveillance of Populations Affected by a Radiation Accident. Nuclear Emergency Situations Improvement of Medical and Health Surveillance. 2017.

determine the causal relationship between radiation and cancer is nearly impossible.[49] Coupled with the finding of thyroid cancer metastasis, however, it seems enhanced screenings are entirely appropriate.

Perinatal mortality rates increased significantly in Fukushima and six neighbouring prefectures after the Fukushima nuclear disaster began, although researchers debate the magnitude of the increase and further study is needed to associate increases with radiation from the catastrophe.[50],[51]

The choice to voluntarily evacuate from areas not considered "exclusion zones", separated families, sometimes permanently, as mothers left to protect their children, while fathers remained due to the necessity of work.

After Fukushima, the International Commission on Radiological Protection made public its report encouraging the growing and eating of contaminated food to protect economic interests, while they also made recommendations for how much radiation people should be exposed to.[52] Yet their models do not fully account for being a child, female or pregnant.

Reprocessing: the dirty end of the nuclear fuel chain

Reprocessing — the cutting up of irradiated reactor fuel rods in a chemical bath to extract plutonium and fissile uranium — involves the annual discharge of tens of millions of gallons of radioactively contaminated liquids and the release of radioactive gases such as krypton, xenon and carbon-14.

A 1990 UK study of the Sellafield reprocessing facility by Martin J. Gardner et a.,l[53] found higher incidences of leukaemia, particularly, non-Hodgkin's lymphoma, among children near the site. It

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[47] Thomas GA, Symonds P. Radiation Exposure and Health Effects - is it Time to Reassess the Real Consequences?. *Clin Oncol (R Coll Radiol)*. 2016;28(4):231-236. doi:10.1016/j.clon.2016.01.007
[48] Tsuda T, Tokinobu A, Yamamoto E, Suzuki E. Thyroid Cancer Detection by Ultrasound Among Residents Ages 18 Years and Younger in Fukushima, Japan: 2011 to 2014. *Epidemiology*. 2016;27(3):316-322. doi:10.1097/EDE.0000000000000385
[49] Tsuda, T. Personal communication. March 2, 2022.
[50] Scherb HH, Mori K, Hayashi K. Increases in perinatal mortality in prefectures contaminated by the Fukushima nuclear power plant accident in Japan: A spatially stratified longitudinal study. *Medicine (Baltimore)*. 2016;95(38):e4958. doi:10.1097/MD.0000000000004958
[51] Körblein A, Küchenhoff H. Perinatal mortality after the Fukushima accident: a spatiotemporal analysis [published online ahead of print, 2019 Jul 29]. *J Radiol Prot*. 2019;39(4):1021-1030. doi:10.1088/1361-6498/ab36a3
[52] Lochard J, Bogdevitch I, Gallego E, et al. ICRP Publication 111 - Application of the Commission's recommendations to the protection of people living in long-term contaminated areas after a nuclear accident or a radiation emergency [published correction appears in Ann ICRP. 2013 Aug;42(4):343]. *Ann ICRP*. 2009;39(3):1-62. doi:10.1016/j.icrp.2009.09.008
[53] Gardner MJ, Snee MP, Hall AJ, Powell CA, Downes S, Terrell JD. Results of case-control study of leukaemia and lymphoma among young people near Sellafield nuclear plant in West Cumbria. BMJ.

concluded that this might be “associated with paternal employment and recorded external dose of whole body penetrating radiation during work at the plant before conception. The association can explain statistically the observed geographical excess. This result suggests an effect of ionising radiation on fathers that may be leukaemogenic in their offspring.”

The findings were disputed in a paper by Doll et al.,[54] which gave credence to a theory also favoured by the Sellafield owners at the time that the cause was a virus brought in by an outside workforce – a theory that remains unsubstantiated.

However, soil samples taken from around Sellafield, and analysed by Bremen University on behalf of Greenpeace, found 23 times the level of Americium-241 at Sellafield compared to the Chernobyl exclusion zone. Inevitably, BNFL, the then owners of Sellafield, dismissed these findings as “scaremongering”, an accusation commonly launched by the nuclear industry, still today, in order to dismiss unfavourable data.

In 2002, a further investigation by Dickinson, HO et al., confirmed the Gardiner conclusions that “Children of radiation workers had a higher risk of leukaemia/non-Hodgkin's lymphoma than other children [rate ratio (RR) = 1.9, 95% confidence interval (CI) 1.0-3.1, p = 0.05]”.[55] The researchers used “a cohort rather than a case-control design, with wider temporal and geographic boundaries, and confirmed the statistical association between father's preconceptional irradiation and child's risk of leukaemia/non-Hodgkin's lymphoma,” and concluded that “The possibility remains that paternal preconceptional irradiation may be a risk factor for leukaemia/non-Hodgkin's lymphoma, and this effect may not be confined to Seascale.”

A 1993 study[56] similarly found elevated rates of childhood leukaemia around the La Hague reprocessing site in France, leading to its lead author, Jean-François Viel, suffering vicious attacks in attempts to discredit his findings and reputation. These attacks worsened after the publication of a second paper the following year.[57]

The main by-product of nuclear power: radioactive waste

1990 Feb 17;300(6722):423-9. doi: 10.1136/bmj.300.6722.423. Erratum in: BMJ. 1992 Sep 19;305(6855):715. PMID: 2107892; PMCID: PMC1662259.

[54] Doll R. The Seascale cluster: a probable explanation. Br J Cancer. 1999 Sep;81(1):3-5. doi: 10.1038/sj.bjc.6690642. PMID: 10487604; PMCID: PMC2374279.

[55] Dickinson HO, Parker L. Leukaemia and non-Hodgkin's lymphoma in children of male Sellafield radiation workers. Int J Cancer. 2002 May 20;99(3):437-44. doi: 10.1002/ijc.10385. PMID: 11992415.

[56] Viel JF, Richardson S, Danel P, Boutard P, Malet M, Barrelier P, Reman O, Carré A. Childhood leukemia incidence in the vicinity of La Hague nuclear-waste reprocessing facility (France). Cancer Causes Control. 1993 Jul;4(4):341-3. doi: 10.1007/BF00051336. PMID: 8347783.

[57] Pobel D, Viel JF. Case-control study of leukaemia among young people near La Hague nuclear reprocessing plant: the environmental hypothesis revisited. BMJ. 1997 Jan 11;314(7074):101-6. doi: 10.1136/bmj.314.7074.101. PMID: 9006467; PMCID: PMC2125632.

The selection of a deep geological repository — the option favoured by most nuclear countries for the management of irradiated reactor fuel — involves ethical as well as scientific challenges.

In the U.S., the selection of the now abandoned Yucca Mountain high-level radioactive waste repository site in Nevada violated the treaty rights of the Western Shoshone on whose tribal land it is located. It also ignored the inevitable contamination of groundwater sources beneath the mountain, which would subsequently harm tribal and agricultural populations downstream.

The US has now turned to "Consolidated Interim Storage" for the "temporary" accommodation of high-level radioactive reactor waste, identifying two largely Hispanic communities in Texas and New Mexico as host sites. The approval process, which was not voluntary, has been challenged in court. However, given their increased sensitivity, any disposal of radioactive wastes in such parking lot-style facilities will put children in the host community at heightened risk of harm.

Elsewhere, the search for a radioactive waste management plan continues, with only Finland currently building a deep geologic repository. The question about harm to future generations remains unresolved, given the challenge of identifying the lethality of the repository contents to populations potentially a hundred thousand years or more into the future.

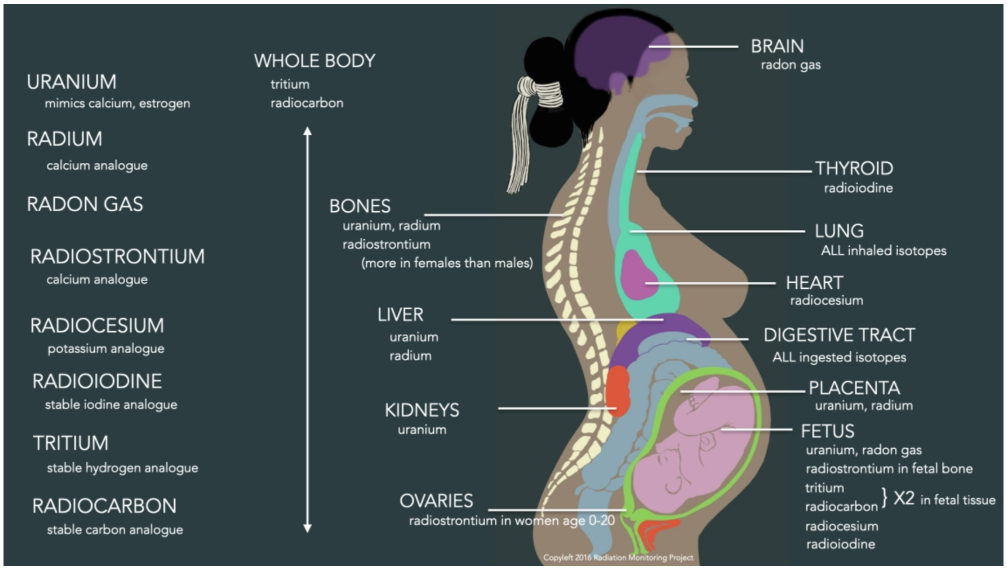
Conclusions

A first and essential step is to acknowledge the connection between radiation exposures from these industries and the negative health impacts observed among children, so that early diagnosis and treatment can be provided. Measures should then be taken to protect communities from further exposures, including a prompt phaseout of nuclear power and its supporting industries.

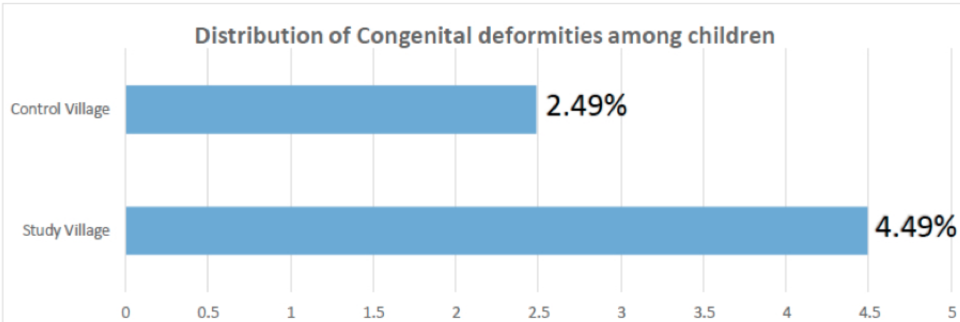
It is further important to observe that, given other socio-economic factors that drive higher deprivation of services in non-homegenous, low income communities of colour, non-White children are at higher risk of negative health outcomes when exposed to radioactive releases, than their White counterparts.

Studies are also urgently needed where there are none, and the findings of independent doctors, scientists and laboratories should be given equal attention and credence as those conducted by industry or government-controlled bodies, whose vested interests surely compromise both their methodologies and conclusions.

Finally, the exercise of precaution is paramount. This means listening to, and taking seriously, the evidence provided by those living close to operating or closed nuclear facilities, rather than silencing their fears using statistically-based denials and uncertainties in the science to deny health impacts and prevent protective actions.



162x91mm (300 x 300 DPI)



79x28mm (300 x 300 DPI)

4 European studies - post KiKK

Körblein A and Fairlie I. French Geocap study confirms increased leukemia risks in young children near nuclear power plants. Int J Cancer. Article published online: 1 Sept 2012. DOI: 10.1002/ijc.27585

Acute leukaemias in under 5s within 5 km of NPPs

Country	Observed	Expected	SIR=O/E	90%CI	p-value
Germany	34	24.1	1.41	1.04-1.88	0.0328
GB	20	15.4	1.30	0.86-1.89	0.1464
Suisse	11	7.9	1.40	0.78-2.31	0.1711
France	14	10.2	1.37	0.83-2.15	0.1506
pooled data	**79**	**57.5**	**1.37**	**1.13-1.66**	**0.0042**

79x55mm (300 x 300 DPI)

BMJ Paediatrics Open

Radioactive releases from the nuclear power sector and implications for child health

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Radioactive releases from the nuclear power sector and implications for child health

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Radiation injuries

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Reference count: 91

Key Points

1. Data on women, pregnant women, children and members of low-income and non-White communities, indicate that exposure to radioactivity may disproportionately harm the health of these demographics.
2. A nuclear disaster releasing large amounts of radioactive isotopes can harm those immediately affected as well as future generations exposed to long-term low radiation doses.
3. Radiation exposure studies often discount the sensitivities of women, children and minorities or apply inappropriate models to assess the impacts.
4. Those studies that focus on the more susceptible populations have recorded significant disproportionate harm to health compared to others in the population.
5. A number of prevailing faulty assumptions about data and research methods often prevent radiation studies from associating radiation exposure with disease increases, especially at low doses.

Abstract

Although radioactivity is released routinely at every stage of nuclear power generation, the regulation of these releases has never taken into account those potentially most sensitive — women, especially when pregnant, and children. From uranium mining and milling, to fuel manufacture, electricity generation and radioactive waste management, children in frontline and Indigenous communities can be disproportionately harmed the most due to often increased sensitivity of developing systems to toxic exposures, the lack of resources, and racial and class discrimination. The reasons for the greater susceptibility of women and children to harm from radiation exposure is not fully understood, but regulatory practices, particularly in the establishment of protective exposure standards, have failed to take this difference into account. Anecdotal evidence within communities around nuclear facilities suggests an association between radiation exposure and increases in birth defects, miscarriages and childhood cancers. In particular a significant number of academic studies tend to ascribe causality to other factors related to diet and lifestyle and dismiss these health indicators as statistically insignificant. In the case of a major release of radiation due to a serious nuclear accident, children are again on the frontlines, with a noted susceptibility to thyroid cancer, which has been found in significant numbers among children exposed both by the 1986 Chornobyl nuclear accident in Ukraine and the 2011 Fukushima-Daiichi nuclear disaster in Japan. The response among authorities in Japan is to blame increased testing, or to reduce testing. More independent studies are needed focused on children, especially those in vulnerable frontline and Indigenous communities. In conducting such studies, greater consideration must be applied to culturally significant traditions and habits in these communities.

Introduction

Radioactivity is released at every stage of nuclear power production, from uranium mining to electricity generation to radioactive waste production. In some of these phases toxic heavy metals are also released into the environment.

Children, women, and particularly pregnant women, living near nuclear production facilities appear to be at disproportionately higher risk of harm from exposure to these releases. Children in poorer often Non-White and Indigenous communities with fewer resources and reduced access to health care are even more vulnerable - an impact compounded by discrimination, socio-economic and cultural factors.

Nevertheless, pregnancy, children and women are underprotected by current regulatory standards that are based on "allowable" or "permissible" doses (permissible does not mean safe[1]) for a "Reference Man". Reference Man is defined as "... a nuclear industry worker 20-30 years of age, [who] weighs 70 kg (154 pounds), is 170 cm (67 inches) tall...is a Caucasian and is a Western European or North American in habitat and custom."[2].

Very early research conducted in the United States in 1945 and 1946 indicated higher susceptibility of pregnancy to radiation exposure. Pregnant dogs injected with radiostrontium had defects in their offspring and yet, "complete results [of these studies] were not made public until 1969.[3]"

By 1960 however, U.S. experts were clearly aware that research indicated higher susceptibility of children, when the Federal Radiation Council (FRC) (established in 1959 by President Eisenhower) briefly considered a definition for "Standard Child" – which they subsequently abandoned in favour of maintaining a Standard Man definition[4] (later renamed Reference Man). The 1960 report also recognized hormones as a radiation "co-carcinogen", which evokes later research indicating that radiation impacts the oestrogenic pathway, although the mechanism is not understood and has been poorly investigated[5].

[1] Early in the nuclear weapons era, a "permissible dose" was more aptly recognized as an "acceptable injury limit," but that language has since been sanitised. See Folkers, C. Disproportionate Impacts of Radiation Exposure on Women, Children, and Pregnancy: Taking Back our Narrative. *J Hist Biol* **54,** 31–66 (2021). https://doi.org/10.1007/s10739-021-09630-z

[2] Lochbaum, D. Reference Man. Gender and Radiation Impact Project. April 2021. https://drive.google.com/file/d/17npIPuVg89EL9ylkPa_jQJAKORhnpS6u/view

[3] Folkers, C. Disproportionate Impacts of Radiation Exposure on Women, Children, and Pregnancy: Taking Back our Narrative. *J Hist Biol* **54,** 31–66 (2021). https://doi.org/10.1007/s10739-021-09630-z AND Freeman, L.J. 1981. Nuclear Witnesses: Insiders Speak Out. New York, Toronto: WW Norton, George J. McLeod Ltd. p. 50, n. 1

[4] Folkers, C. Disproportionate Impacts of Radiation Exposure on Women, Children, and Pregnancy: Taking Back our Narrative. *J Hist Biol* **54,** 31–66 (2021). https://doi.org/10.1007/s10739-021-09630-z

[5] Fucic, A., and M. Gamulin. 2011. Interaction Between Ionizing Radiation and Estrogen: What We Are Missing?' Medical Hypotheses 77: 966–969.

And while the current U.S. Environmental Protection Agency (EPA) toxic exposure guidance recognizes an enhanced early lifecycle susceptibility to a number of mutagens[6], recommending a risk factor increase of 10 after birth and before the age of 2 for some of these toxics[7], radiation exposure standards are still based on Reference Man.

Differing impacts based on gender occur for a range of chemicals and various exposure scenarios. In some cases males are more susceptible than females, while the reverse is also seen[8]. For ionizing radiation in particular, data from the survivors of the atomic bombings in Japan show "women from the same age-at-exposure cohort (26–30 years) suffered 50% more cancer…compared to the males".[9] The latest data from the atomic bombing survivor cohorts in Japan associate radiation exposure *in utero* with solid cancer mortality for adult females, but not males.[10]

Since female cumulative baseline rates for most cancer types are lower than male[11], exposure to radiation may be erasing a woman's potential natural cancer resistance, while also increasing her risk relative to a man's. However, not enough research has been done in this area to be sure.

Current U.S. regulations allow a radiation dose to the public (100 mrem per year) which poses a lifetime cancer risk to the Reference Man model of 1 person in 143. This is despite the EPA's acceptable risk range for lifetime cancer risk from toxics being 1 person in 1 million to 1 person in 10,000[12]. As noted by the EPA, this gives radiation a "privileged pollutant" status[13]. Additionally, biokinetic models for radioistopes are not sex-specific. A male model is still used

[6] Barton HA, Cogliano VJ, Flowers L, Valcovic L, Setzer RW, Woodruff TJ. Assessing susceptibility from early-life exposure to carcinogens. *Environ Health Perspect*. 2005;113(9):1125-1133. doi:10.1289/ehp.7667

[7] U.S. EPA. Supplemental Guidance for Assessing Susceptibility from Early-Life Exposure to Carcinogens. U.S. Environmental Protection Agency, Washington, DC, EPA/630/R-03/003F, 2005, p 33.

[8] Torres-Rojas C, Jones BC. Sex Differences in Neurotoxicogenetics. *Front Genet*. 2018;9:196. Published 2018 Jun 5. doi:10.3389/fgene.2018.00196

[9] Olson M. Disproportionate impact of radiation and radiation regulation. *Interdisciplinary Science Reviews*. 2019 Apr 3;44(2):131-9.

[10] Sugiyama, H., M. Misumi, R. Sakata, A. V. Brenner, M. Utada, and K. Ozasa. (2021). "Mortality among individuals exposed to atomic bomb radiation in utero: 1950–2012." European Journal of Epidemiology 36(4): 415–428. doi: 10.1007/s10654-020-00713-5.

[11] Dorak MT, Karpuzoglu E. Gender differences in cancer susceptibility: an inadequately addressed issue. *Front Genet*. 2012;3:268. Published 2012 Nov 28. doi:10.3389/fgene.2012.00268 AND National Academy of Sciences, National Research Council. 2006. Health Risks from Exposure to Low Levels of Ionizing Radiation, Health Risks from Exposure to Low Levels of Ionizing Radiation (BEIR VII Phase 2). Board on Radiation Effects Research. Division on Earth and Life Studies, Table ES-1. Washington, DC: National Academies Press. https://doi.org/10.17226/13388

[12] https://semspub.epa.gov/work/11/176250.pdf

[13] Skrzycki, C. Going Nuclear over the Ground Rules on Contamination. The Washington Post. May 9, 1997. https://www.washingtonpost.com/archive/business/1997/05/09/going-nuclear-over-the-ground-rules-on-contamination/5ce773f2-b415-4f62-810d-d9c5b94d6ab6/

for females. The models are also not fully age-dependent.[14] Radiation damage models also fail to account for a whole host of childhood and pregnancy damage.[15]

And yet, there are known "windows of susceptibility" in a lifetime, "includ[ing] periods of active cell differentiation and growth in the womb and in early childhood as well as adolescence, when the brain is continuing to develop" during which "[c]hemicals can act like hormones and drugs to disrupt the control of development and function at very low doses…[i]n some cases, a susceptibility to disease also can persist long after the initial insult or exposure has ended"[16]

Women and children in underserved communities are at still greater risk because of unique exposure pathways, and systemic inequities. Traditional lifestyle and cultural patterns can also lead to increases in exposure. In the case of some Native Americans, exposure to toxics and radiation has been multi-generational, enduring over a period of 150 years.[17]

In an exploration of the studies, we find a notable lack of in-depth, independent research looking specifically at children, as well as the wider population in Indigenous or minority communities, those often on the frontlines of radiation exposure. Uncertainties caused by this lack of study are used by officials to underprotect those most at risk.

We also find a marked contrast between the conclusions of some of the studies and the anecdotal evidence on the ground.

Most of the primary research that *has* focused on the susceptibilities of women and children has consistently indicated disproportionate impacts, even among those possibly exposed to lower radiation doses. Impacts include increases in childhood cancers, particularly leukaemia and central nervous system cancers, impaired neural development, lower IQ, birth defects, respiratory difficulties, cardiovascular dysfunction and perinatal mortality. Rapid cell division is among the development processes thought to account for some of this susceptibility.

However, many studies are unable to link these adverse outcomes to radioactivity because the studies' authors tend to use several faulty assumptions:

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[14] Jokisch, Derek. Challenges and Opportunities for Dosimetry in Low-Dose Radiation Research video presentation. Developing a Long-Term Strategy for Low-Dose Radiation Research in the United States. Nuclear and Radiation Studies Board. National Academy of Sciences. January 24, 2022. time: 1:19:23 https://www.nationalacademies.org/event/01-24-2022/developing-a-long-term-strategy-for-low-dose-radiation-research-in-the-united-states-meeting-7-january-24-25-2022

[15] Folkers, C. Disproportionate Impacts of Radiation Exposure on Women, Children, and Pregnancy: Taking Back our Narrative. *J Hist Biol* **54,** 31–66 (2021). https://doi.org/10.1007/s10739-021-09630-z

[16] Birnbaum, Linda S. Researchers Find New Risks in Low-Dose Chemical Exposure. American Association for the Advancement of Science https://www.aaas.org/news/linda-s-birnbaum-researchers-find-new-risks-low-dose-chemical-exposure

[17] Center for Native EH Equity. 2016. Centers for Excellence in Environmental Health Disparities Research. Native Environmental Health Equity Newsletter: Native EH Equity Addresses Mining Impacts on Native Lands in the West. Issue 1.

1) ”*doses will be too low to create an effect*” — a beginning assumption ensuring poor hypothesis formation and study design.[18] Therefore, when an effect is found, radioactivity has been predetermined not to have an association with the effect. This exclusion often leads to an inability to find an alternate associated disease agent;

2) “*small negative findings matter*”— In fact, what matters are positive findings or very large negative findings;[19]

3)“*statistical non-significance means a lack of association between radiation exposure and disease”* — a usage a number of scientists in various disciplines now call “ludicrous”;[20]

4) “*potential bias or confounding factors are reasons to dismiss low dose studies*” — In fact, when assessing low dose impacts, researchers should take care not to dismiss studies with these issues and researchers should minimise use of quality score ranking.[21]

Consequently, we examine and referenced studies even if they contained such faulty assumptions because they still indicated increases in certain diseases, such as some leukaemias, known to be caused by radiation exposure. Additionally, few alternative explanations were offered in the conclusions of these studies, meaning radiation exposure might still have been the cause.

Figure 1. Selected radioisotopes: where they travel and primarily collect in the body[22]

Uranium mining and racial discrimination

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[18] Wing S, Richardson DB, Hoffmann W. Cancer risks near nuclear facilities: the importance of research design and explicit study hypotheses. *Environ Health Perspect*. 2011;119(4):417-421. doi:10.1289/ehp.1002853

[19] Ian Fairlie I. The Other Report on Chernobyl: An Independent Scientific Evaluation of the Health-Related Effects of the Chernobyl Nuclear Disaster. Vienna: Weiner Umweltanhaltschaft. 2016:98-100.

[20] Amrhein V, Greenland S, McShane B. Scientists rise up against statistical significance.

[21] Preston, D. Future of Low Dose Risk Modelling. Developing a Long-Term Strategy for Low-Dose Radiation Research in the United States. Nuclear and Radiation Studies Board. National Academy of Sciences. November 16, 2021. Time: 2:30:40 and 3:06:00. https://www.nationalacademies.org/event/11-16-2021/developing-a-long-term-strategy-for-low-dose-radiation-research-in-the-united-states-meeting-6-november-16-17-2021

[22] We would like to recognize and thank the Radiation Monitoring Project for this image. RMP hosted workshops on understanding and monitoring radioactive contamination in the environment by purchasing and distributing radiation detectors to contaminated and frontline communities, focusing on Native Americans. RMP is a collaboration between Diné No Nukes, Nuclear Energy Information Service & Sloths Against Nuclear State.

Uranium mining contributes significantly to the wide dispersal of radioactive waste streams into the air, water and soil. Uranium mining also leaves behind a massive debris field of discarded radioactive residues, rocks and heavy metals, known as tailings.

Heavy metals are also released by uranium mining and these can be as toxic, if not more so, than the radioactive elements. The 1960 FRC report recognized radiation as a co-carcinogen with not only hormones but also viruses and chemicals, indicating synergistic impacts that have rarely been investigated. One study by Anton V. Korsakov et al., looking at medical impacts of the 1986 Chornobyl nuclear power plant disaster in Ukraine, found that multiple congenital malformations were much higher in areas of combined contamination, suggesting an additive and potentially synergistic effect between radioactive and chemical pollutants.[23]

In the United States, Native American communities have constituted the majority of the uranium mining workforce. In the American Southwest, Navajo Nation community members have experienced increases in a number of diseases and lingering internal contamination from uranium mine waste among neonates and children. [24],[25],[26],[27] Native Americans also present with chronic ailments – such as kidney disease and hypertension – linked with living near and contact with uranium mine waste.[28]

Additionally, comparing uranium mining health data from one race to another should be done with caution as "[t]he increased toxicity [of mining exposure] to Native miners underscores the potential for unique sensitivities to toxicants within the Native community as compared to all races results, questioning the derivation of standards on the basis of data collected from other populations."[29]

It is also worth noting that some Native American communities are living with a 150-year health legacy of potential exposure to radioactive and heavy metal mine waste. Studies on humans,

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[23] Korsakov AV, Geger EV, Lagerev DG, Pugach LI, Mousseau TA. *De novo* congenital malformation frequencies in children from the Bryansk region following the Chernobyl disaster (2000-2017). *Heliyon*. 2020;6(8):e04616. Published 2020 Aug 17. doi:10.1016/j.heliyon.2020.e04616

[24] Erdei E, Shuey C, Pacheco B, Cajero M, Lewis J, Rubin RL. Elevated autoimmunity in residents living near abandoned uranium mine sites on the Navajo Nation. *J Autoimmun*. 2019;99:15-23. doi:10.1016/j.jaut.2019.01.006

[25] Cooper KL, Dashner EJ, Tsosie R, Cho YM, Lewis J, Hudson LG. Inhibition of poly(ADP-ribose)polymerase-1 and DNA repair by uranium. *Toxicol Appl Pharmacol*. 2016;291:13-20. doi:10.1016/j.taap.2015.11.017

[26] Harmon ME, Lewis J, Miller C, et al. Residential proximity to abandoned uranium mines and serum inflammatory potential in chronically exposed Navajo communities. *J Expo Sci Environ Epidemiol*. 2017;27(4):365-371. doi:10.1038/jes.2016.79

[27] Lewis J, Hoover J, MacKenzie D. Mining and Environmental Health Disparities in Native American Communities. *Curr Environ Health Rep*. 2017;4(2):130-141. doi:10.1007/s40572-017-0140-5

[28] Ibid.

[29] Ibid.

such as Korsakov et. al, and additional studies on radioactivity and animals[30],[31],[32] indicate that legacy exposures such as these can leave descendants of a community more susceptible to damage from future exposures than their parents were.

An examination of Navajo babies born between 1964 and 1981 showed that congenital anomalies, developmental disorders, and other adverse birth outcomes were associated with the mother living near uranium mines and wastes.[33] The results of this study, published in 1992, were not followed up until 2010 with the establishment of the Navajo Birth Cohort study, a community-based and -driven initiative that examines the impact of chronic exposure to mine wastes on birth outcomes.[34]

Historic and recent official research has, on the whole, been systemically racist by failing to account for culturally-specific exposure scenarios to Navajo. These include frequent contact with contaminated lands, waters and, in some cases, a nearly 100% reliance on locally grown and sourced foods[35,36], as well as failure to consider doses to Navajo Nation community members from the Trinity explosion—the first detonation of an atomic device.[37] Some research teams have attempted to address systemic racism by partnering with local community members and integrating local knowledge.[38]

In Jadugoda, India, where six uranium mines operate, the first opening in 1957, those affected are Indigenous peoples from the Santhal, Munda and Ho tribes. A local organisation,

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[30] Goncharova, R., and N. Ryabokon. 1998. Results of Long-term Genetic Monitoring of Animal Populations Chronically Irradiated in the Radio-contaminated Areas. In Research Activities on the Radiological Consequences of the Chernobyl NPS Accident and Social Activities to Assist the Survivors from the Accident (Report of an International Collaborative Work under the Research Grant of the Toyota Foundation in 1995–1997), ed. T. Imanaka, 194–202. http://www.rri.kyoto-u.ac.jp/NSRG/reports/kr21/kr21pdf/kr21.pdf.

[31] Baker, R. J., B. Dickins, J.K. Wickliffe, F. Khan, S. Gaschak, K.D. Makova, and C.D. Phillips. 2017. Elevated Mitochondrial Genome Variation after 50 Generations of Radiation Exposure in a Wild Rodent. Evolutionary Applications 10 (8): 784–791.

[32] Omar-Nazir, L., X. Shi, A. Moller, T. Mousseau, S. Byun, S. Hancock, C. Seymour, and C. Mothersill. 2018. Long-term Effects of Ionizing Radiation after the Chernobyl Accident: Possible Contribution of Historic Dose. Environmental Research 165: 55–62.

[33] Shields LM, Wiese W, Skipper B, Charley B, Banally L. Navajo birth outcomes in the Shiprock uranium mining area. Health Phys. 1992;63(5):542–551. doi: 10.1097/00004032-199211000-00005

[34] Lewis J, Hoover J, MacKenzie D. Mining and Environmental Health Disparities in Native American Communities. *Curr Environ Health Rep*. 2017;4(2):130-141. doi:10.1007/s40572-017-0140-5

[35] ibid

[36] DeLemos J, Rock T, Brugge D, Slagowski N, Manning T, Lewis J. Lessons from the Navajo: assistance with environmental data collection ensures cultural humility and data relevance. *Prog Community Health Partnersh*. 2007;1(4):321-326. doi:10.1353/cpr.2007.0039

[37] Cahoon EK, Zhang R, Simon SL, Bouville A, Pfeiffer RM. Projected Cancer Risks to Residents of New Mexico from Exposure to Trinity Radioactive Fallout [published correction appears in Health Phys. 2021 Jan;120(1):97]. *Health Phys*. 2020;119(4):478-493. doi:10.1097/HP.0000000000001333

[38] DeLemos J, Rock T, Brugge D, Slagowski N, Manning T, Lewis J. Lessons from the Navajo: assistance with environmental data collection ensures cultural humility and data relevance. *Prog Community Health Partnersh*. 2007;1(4):321-326. doi:10.1353/cpr.2007.0039

Jharkhandi Organisation Against Radiation, has been documenting strange health anomalies in the community for years, including deformities and birth defects.

Their observations were supported by an independent study[39] of the Jadugoda community conducted in 2007 by Indian Doctors for Peace and Development, which found that “babies from mothers, who lived near uranium mining operation area [sic] suffered a significant increase in congenital deformities. While 4.49% mothers living in the study villages reported that children with congenital deformities were born to them, only 2.49% mothers in reference villages fell under this category.”[40]

Not only deformities, but also deaths were higher, the study found. “Increased number of children in the study villages is [*sic*] dying due to congenital deformities. Out of mothers who have lost their children after birth, 9.25% mothers in the study villages reported congenital deformities as the cause of death of their children as compared to only 1.70% mothers in the reference villages.”[41]

The authors concluded that “The finding of the study confirms the hypotheses that the health of indigenous people around uranium mining is more vulnerable to certain health problems”.[42]

Figure 2. Congenital deformities among babies from mothers who lived near the Jadugoda uranium mining operations.

However, other studies contradict these conclusions. A 2013 study[43] by A C Patra et al., concluded that “the water is safe for drinking”. And, a study[44] by scientists from India’s Bhabha Atomic Research Centre, came to a similar conclusion. However, these studies are deficient in many ways, limiting their research to dose reconstruction rather than health outcomes and failing to consider inhalation or ingestion of radionuclides, other than from drinking water. Furthermore, the association with the Atomic Research Centre raises questions about conflict of interest.

People living in the town of Arlit in Niger, and those working in the huge majority French-owned uranium mine nearby, are exposed on a daily basis to levels of radioactivity higher than those

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[39] Rahman S. et al. “Study on health status of indigenous people around Jadugoda uranium mines in India.” Indian Doctors for Peace and Development, 2007.
[40] Ibid.
[41] Ibid.
[42] Ibid.
[43] Patra AC, Mohapatra S, Sahoo SK, Lenka P, Dubey JS, Tripathi RM, Puranik VD. Age-dependent dose and health risk due to intake of uranium in drinking water from Jaduguda, India. Radiat Prot Dosimetry. 2013 Jul;155(2):210-6. doi: 10.1093/rpd/ncs328. Epub 2013 Mar 22. PMID: 23525912.
[44] N.K. Sethy et al, Assessment of Natural Uranium in the Ground Water around Jaduguda Uranium Mining Complex, India,. Journal of Environmental Protection. August 27, 2011.

found in the Chornobyl exclusion zone. Independent studies in Arlit[45], beginning in 2003, found radioactively contaminated metals discarded from the mine routinely used in households, where children were exposed.

An independent study commissioned by the European Parliament and published in 2010, looked at health and environmental legacy conditions around uranium mines in both Gabon and Niger and found, in the case of Niger, that “waste dumps and related processing facilities are posing a severe environmental and health hazard to the local population”.[46] It further noted that “There is evidence of radioactive contamination of local water supplies, and contaminated dust,” and that “Contaminated construction materials have been sold on local markets and were found in dwellings and in the towns”.[47] However, despite observations of the risks from multiple scientific sources, there is a paucity of actual health studies. The health outcomes are largely recorded anecdotally, by activists on the ground such as the Arlit-based NGO, Aghirin’ Man.

Aghirin’ Man founder, Almoustapha Alhacen, himself a former uranium miner, has reported that “More than 45 million tons of uranium tailings are stored in the open air. People are dying of cancerous diseases, the wildlife and livestock is lost and large areas of agriculture are affected by the draining of 70% of the fossil groundwater layer.”[48]

In Australia, uranium contaminates drinking water around uranium mine sites at rates far higher than recommended. Aboriginal communities, most likely to inhabit land around these facilities, suffer from increases in cancers and stillbirths according to the findings described below.

A 2019 Australian government study[49] found increases in low birth weight, foetal death and cancers, but a “lack of evidence” that alcohol and tobacco use, and a high-fat diet, could explain the full increase in diseases. Radiation, which could have been a responsible agent, was eliminated because the researchers considered that the doses were too low to explain the remaining disease increases not attributable to non-radiation exposure factors. This was despite the known connection between radiation exposure and low birth weight and cancers. This conclusion left the community with unexplained disease increases, a pattern seen all too often in radiation health studies.

[45] B. Chareyron, CRIIRAD, AREVA : Du discours à la réalité / L’exemple des mines d’uranium du Niger, January 2008, 5.24.0.00/08 (NIGER)
[46] Veit, Sebastian, Srebotnjak, Tanja, Potential use of radioactively contaminated materials in the construction of houses from open pit uranium mine materials in Gabon and Niger, European Parliament, November 19, 2010.
[47] Ibid.
[48] Thiam, Ibrahima. The Fight for Uranium. Uranium Mining. Impact on Health & Environment. Rosa Luxemburg Stiftung. April 2014.
[49] Guthridge S et al., Gunbalanya-Kakadu disease cluster investigation. Final report, Northern Territory Government, EDOC2020/34649, September 2019.

In her analysis, Rosalie Schultz states that “We owe it to Aboriginal people living near mines to understand and overcome what’s making them sick”,[50] and further points out that “Development of the Ranger mine entailed nullification of veto rights, disempowering Aboriginal communities and threatening their livelihoods. With mining came royalty money, expensive commodities, money-hunger and alcohol”.

These examples serve to highlight the tension between the often strong anecdotal evidence and the common failure to attribute the causal factor to a potential exposure source already linked to the outcome of interest in other populations.

Routine radioactive releases from nuclear power plants

Nuclear power plants routinely release radioactivity as part of daily operation. In 2008, a landmark case-control study was published in Germany[51], known as the KiKK study.

It revealed an unsettling 1.6-fold increase in all cancers and a 2.2-fold increase in leukaemias among children under five years old living within 5km of operating nuclear power plants.

In general, the incidences were higher the closer the children lived to the nuclear plant. The KiKK findings were backed up by other studies,[52] and a meta-analysis.[53]

However, the authors concluded that their findings were “unexplainable” because the doses were assumed to be too low to cause cancer. But UK radiation researcher, Dr. Ian Fairlie, hypothesises that sudden large spikes in radiation releases during reactor refuelling resulted in higher doses. These could account for higher rates of leukaemia among children.[54]

Fairlie further posits “the observed high rates of infant leukaemias may be a teratogenic effect from radionuclides incorporated during pregnancy.”[55]

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[50] Schultz R. Investigating the health impacts of the Ranger uranium mine on Aboriginal people. Med J Aust. 2021 Aug 16;215(4):157-159.e1. doi: 10.5694/mja2.51198. Epub 2021 Aug 1. PMID: 34333775.

[51] Kaatsch P, Spix C, Schulze-Rath R, Schmiedel S, Blettner M. Leukaemia in young children living in the vicinity of German nuclear power plants. Int J Cancer. 2008 Feb 15;122(4):721-6. doi: 10.1002/ijc.23330. PMID: 18067131.

[52] Fairlie I, Körblein A. Review of epidemiology studies of childhood leukaemia near nuclear facilities: commentary on Laurier et al. *Radiat Prot Dosimetry*. 2010;138(2):194-197. doi:10.1093/rpd/ncp246

[53] Baker PJ, Hoel D: Meta-analysis of standardized incidence and mortality rates of childhood leukemias in proximity to nuclear facilities. Eur J Cancer Care. 2007, 16: 355-363. 10.1111/j.1365-2354.2007.00679.

[54] Fairlie I. A hypothesis to explain childhood cancers near nuclear power plants, Journal of Environmental Radioactivity 133 (July 2014): 10-17.

[55] Fairlie I. Commentary: childhood cancer near nuclear power stations. Environ Health. 2009 Sep 23;8:43. doi: 10.1186/1476-069X-8-43. PMID: 19775438; PMCID: PMC2757021.

Other studies of natural and manmade background radiation associate childhood cancers with doses that are much lower than these spikes, but delivered continuously.[56] Taken together, these studies indicate that unique sensitivity to adverse effects of radiation exposure exists during pregnancy.

Table 1. Pooled analysis of leukaemias in children under 5 years of age within 5 km of nuclear reactors in Europe. Used with permission of [Ian Fairlie]().

Catastrophic radioactive waste releases

There have been at least three catastrophic releases of radioactivity from civilian nuclear reactors due to meltdowns: the 1979 Three Mile Island (TMI) disaster in the U.S., the 1986 Chornobyl disaster in Ukraine and the 2011 Fukushima, Japan nuclear disaster.

During the TMI crisis, there were 24 spontaneous abortions or stillbirths among pregnant women who were living within five miles of the nuclear facility and in their first four months of pregnancy. The expected number should be closer to twelve. The researchers of a study examining this, posit this may be due to stress (measured by number of evacuation days), but live births had equivalent evacuation days to abortions or stillbirths.[57]

Radiation from the TMI catastrophe was also associated with childhood leukaemia, although the study found only a small number of cases. Interestingly the study authors note an association with radiation exposure and all childhood cancers was also present before the catastrophe, albeit with wide confidence intervals. The authors recognize this increase, particularly leukaemia, as "compatible with increases reported near some other nuclear installations…" "but, in view of the low exposures, radiation is considered an unlikely cause…,"[58] yet the authors cite seven additional studies that found this effect. An alternative explanation has yet to be revealed even as more recent studies have indicated increases of childhood leukaemias around operating nuclear facilities and in levels of higher background radiation (see above).

Outcomes in the Former Soviet States (FSS) from initial exposure to Chornobyl radioactive fallout include thyroid cancers (predominantly among those exposed during childhood) and significant increases in leukaemia among children who were in utero or who were under six

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[56] Spycher, B.D., J.E. Lupatsch, M. Zwahlen, M. Röösli, F.K. Niggli, M.A. Grotzer, J. Rischewski, M. Egger, and C.E. Kuehni. 2015. Ionizing Radiation and the Risk of Childhood Cancer: A Census- Based Nationwide Cohort Study. Environmental Health Perspectives. https://doi.org/10.1289/ehp. 1408548. AND Kendall, G.M., M.P. Little, R. Wakeford, K.J. Bunch, J.C. Miles, T.J. Vincent, J.R. Meara, and M.F. Murph. 2013. A Record-based Case–control Study of Natural Background Radiation and the Inci- dence of Childhood Leukaemia and Other Cancers in Great Britain during 1980–2006. Leukemia 27: 3–9

[57] Goldhaber MK, Staub SL, Tokuhata GK. Spontaneous abortions after the Three Mile Island nuclear accident: a life table analysis. *Am J Public Health*. 1983;73(7):752-759. doi:10.2105/ajph.73.7.752

[58] Hatch MC, Beyea J, Nieves JW, Susser M. Cancer near the Three Mile Island nuclear plant: radiation emissions. *Am J Epidemiol*. 1990;132(3):397-417. doi:10.1093/oxfordjournals.aje.a115673

years of age at the time of the Chornobyl catastrophe[59]. Also found were increases in radiation-induced organic mental disorders.[60]

Among those continuing to live in Chornobyl-contaminated areas in the FSS, we see increases in cardiovascular disorders[61],[62] decreased lung function [63],[64] defects of the lens of the eye [65], and significantly increased rates of conjoined twins, teratomas, neural tube defects, microcephaly, and microphthalmia.[66] Further, research indicates significantly higher birth defects—some de novo— in the Chornobyl-contaminated Bryansk region. Projections indicate that certain birth defects will increase in the next few years.[67]

The Chornobyl disaster produced a phenomenon known as “Chornobyl heart”, where children were born with multiple heart defects – now being observed among children exposed as a result of the Fukushima catastrophe.[68] Some of these impacts occur at low, chronic doses.

Outside of the FSS, children born in regions of Sweden with higher Chornobyl fallout performed worse in secondary school – particularly in maths – and had more behavioural problems.[69] Similarly, in Norway, in utero exposure to Chornobyl radiation is associated with significantly lower verbal IQ, verbal working memory, and executive functioning.[70],[71]

In Central Europe, studies observed a statistically significant increase in childhood leukaemias.[72] Perinatal mortality increased in European and FSS countries after the Chornobyl

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[59] International Consortium for Research on the Health Effects of Radiation Writing Committee and Study Team, Davis S, Day RW, et al. Childhood leukaemia in Belarus, Russia, and Ukraine following the Chernobyl power station accident: results from an international collaborative population-based case-control study. *Int J Epidemiol*. 2006;35(2):386-396. doi:10.1093/ije/dyi220

[60] Nyagu AI, Loganovsky KN, Loganovskaja TK, Repin VS, Nechaev SY. Intelligence and brain damage in children acutely irradiated in utero as a result of the Chernobyl accident. KURRI KR. 2002;79:202-30.

[61] Bandazhevsky YI, Lelevich VV. Clinical and experimental aspects of the effect of incorporated radionuclides upon the organism. Belarus (UDC 616–092: 612.014. 481/. 482) Gomel. 1995:128.

[62] Bandazhevskaya GS. The State of Cardiac Activity among Children Living in Areas Contaminated with Radionuclides/Medical Aspects of Radioactive Impact on the Population Living in the Contaminated Territories after the Chernobyl Accident: Proceedings of the International Scientific Symposium. InProceedings of the International Scientific Symposium 1994.

[63] Svendsen ER, Kolpakov IE, Stepanova YI, et al. 137Cesium exposure and spirometry measures in Ukrainian children affected by the Chernobyl nuclear incident. *Environ Health Perspect*. 2010;118(5):720-725. doi:10.1289/ehp.0901412

[64] Svendsen ER, Kolpakov IE, Karmaus WJ, et al. Reduced lung function in children associated with cesium 137 body burden. *Ann Am Thorac Soc*. 2015;12(7):1050-1057. doi:10.1513/AnnalsATS.201409-432OC

[65] Day R, Gorin MB, Eller AW. Prevalence of lens changes in Ukrainian children residing around Chernobyl. *Health Phys*. 1995;68(5):632-642. doi:10.1097/00004032-199505000-00002

[66] Wertelecki W, Yevtushok L, Zymak-Zakutnia N, et al. Blastopathies and microcephaly in a Chornobyl impacted region of Ukraine. *Congenit Anom (Kyoto)*. 2014;54(3):125-149. doi:10.1111/cga.12051

[67] Korsakov AV, Geger EV, Lagerev DG, Pugach LI, Mousseau TA. *De novo* congenital malformation frequencies in children from the Bryansk region following the Chernobyl disaster (2000-2017). *Heliyon*. 2020;6(8):e04616. Published 2020 Aug 17. doi:10.1016/j.heliyon.2020.e04616

catastrophe,[73] and increases in trisomy 21 were found in Berlin and Belarus in 1987/1988. The cases coincided with exposure to Chornobyl fallout.[74]

Perinatal mortality rates increased significantly in Fukushima and six neighbouring prefectures after the Fukushima nuclear disaster began, although researchers debate the magnitude of the increase and further study is needed to associate increases with radiation from the catastrophe.[75],[76]

After Fukushima, the International Commission on Radiological Protection made public its report encouraging the growing and eating of contaminated food to protect economic interests, while they also made recommendations for how much radiation people should be exposed to.[77] Yet their models do not fully account for being a child, female or pregnant.

Thyroid cancers among those exposed to Fukushima radiation as children have increased 20 times the expected rate, with about 80% metastasizing[78] – indicating increased severity of the cancer and suggesting screening and surgery was necessary.

Despite this, SHAMISEN, a project funded by the European Commission, has recommended

[68] Murase K, Murase J, Mishima A. Nationwide Increase in Complex Congenital Heart Diseases After the Fukushima Nuclear Accident. *J Am Heart Assoc*. 2019;8(6):e009486. doi:10.1161/JAHA.118.009486

[69] Almond D, Edlund L, Palme M. Chernobyl's subclinical legacy: prenatal exposure to radioactive fallout and school outcomes in Sweden. The Quarterly journal of economics. 2009 Nov 1;124(4):1729-72.

[70] Heiervang KS, Mednick S, Sundet K, Rund BR. Effect of low dose ionizing radiation exposure in utero on cognitive function in adolescence. *Scand J Psychol*. 2010;51(3):210-215. doi:10.1111/j.1467-9450.2010.00814.x

[71] Heiervang KS, Mednick S, Sundet K, Rund BR. The Chernobyl accident and cognitive functioning: a study of Norwegian adolescents exposed in utero. *Dev Neuropsychol*. 2010;35(6):643-655. doi:10.1080/87565641.2010.508550

[72] Hoffmann W. Has fallout from the Chernobyl accident caused childhood leukaemia in Europe? A commentary on the epidemiologic evidence. *Eur J Public Health*. 2002;12(1):72-76. doi:10.1093/eurpub/12.1.72

[73] Korblein A. Strontium fallout from Chernobyl and perinatal mortality in Ukraine and Belarus. *Radiats Biol Radioecol*. 2003;43(2):197-202.

[74] Sperling K, Neitzel H, Scherb H. Evidence for an increase in trisomy 21 (Down syndrome) in Europe after the Chernobyl reactor accident. *Genet Epidemiol*. 2012;36(1):48-55. doi:10.1002/gepi.20662

[75] Scherb HH, Mori K, Hayashi K. Increases in perinatal mortality in prefectures contaminated by the Fukushima nuclear power plant accident in Japan: A spatially stratified longitudinal study. Medicine (Baltimore). 2016;95(38):e4958. doi:10.1097/MD.0000000000004958

against systematic thyroid screening after nuclear catastrophes, claiming over-diagnosis and psychosocial impact can result.[79]

Although it is correct that in some countries apparently high levels of undiagnosed thyroid anomalies exist without clinical symptoms, banning thyroid screening altogether after nuclear disasters such as Fukushima denies those exposed the essential medical treatment that could catch aggressive cancers early.

The suggestion that medical examinations are psychologically scarring[80] has sometimes been proffered as a justification for avoiding looking for health impacts from radiation exposure after a nuclear accident. Fewer tests have led to fewer findings in some of the more recent studies. As paediatrician Dr. Alex Rosen wrote for the International Physicians for the Prevention of Nuclear War March 2021 edition of *Forum* magazine: “Fukushima Medical University, which is in charge of the study, has been sending staff to schools in the prefecture for years to educate children about their “right not to participate” and the “right not to know”. On the study forms, there is now a prominent “opt-out” option for people who wish to be removed from the screening. FMU seems to encourage people to opt out of the study.”

Some advocates of reduced screening point to studies from South Korea, which blame an “epidemic” of thyroid cancers on increased screening. But data from Japan should not be compared to data from this South Korean study because the study *excluded* participants younger than 20 years and only 2% were in the 20-29 age range.[81] Conversely, the Fukushima health management survey (FHMS), is examining those who were under 18 years of age at exposure.[82]

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[76] Körblein A, Küchenhoff H. Perinatal mortality after the Fukushima accident: a spatiotemporal analysis [published online ahead of print, 2019 Jul 29]. J Radiol Prot. 2019;39(4):1021-1030. doi:10.1088/1361-6498/ab36a3

[77] Lochard J, Bogdevitch I, Gallego E, et al. ICRP Publication 111 - Application of the Commission's recommendations to the protection of people living in long-term contaminated areas after a nuclear accident or a radiation emergency [published correction appears in Ann ICRP. 2013 Aug;42(4):343]. Ann ICRP. 2009;39(3):1-62. doi:10.1016/j.icrp.2009.09.008

[78] Hiranuma Y. Fukushima Thyroid Examination Fact Sheet: September 2017. dent. 2012;11:11.

[79] SHAMISEN Consortium. In collaboration with EU OPERRA and IS Global. Recommendations and Procedures for Preparedness and Health Surveillance of Populations Affected by a Radiation Accident. Nuclear Emergency Situations Improvement of Medical and Health Surveillance. 2017.

[80] Thomas GA, Symonds P. Radiation Exposure and Health Effects - is it Time to Reassess the Real Consequences?. Clin Oncol (R Coll Radiol). 2016;28(4):231-236. doi:10.1016/j.clon.2016.01.007

[81] Ahn HS, Kim HJ, Kim KH, et al. Thyroid Cancer Screening in South Korea Increases Detection of Papillary Cancers with No Impact on Other Subtypes or Thyroid Cancer Mortality. *Thyroid*. 2016;26(11):1535-1540. doi:10.1089/thy.2016.0075

[82] Takamura N, Orita M, Saenko V, Yamashita S, Nagataki S, Demidchik Y. Radiation and risk of thyroid cancer: Fukushima and Chernobyl. *Lancet Diabetes Endocrinol*. 2016;4(8):647. doi:10.1016/S2213-8587(16)30112-7. https://www.thelancet.com/journals/landia/article/PIIS2213-8587(16)30112-7/fulltext#gr1

Researchers also claim that any increasing thyroid cancer incidence rates in Japan are not due to radiation exposure because the age pattern of thyroid cancers arising in Japan after Fukushima differs from that arising after Chornobyl in the former USSR countries.[83]

Five years after the Chornobyl disaster began, Belarus data indeed show a large increase in thyroid cancer diagnoses in those aged 0-4 at time of exposure[84] (AE), unlike the Fukushima data. However, the pattern[85] in Ukraine and Russia *is* similar to the Fukushima data, which show increasing disease among younger age groups as more years pass. Ukraine and Russia, as with the Fukushima data, only demonstrated a high thyroid cancer incidence in age group 0-4 AE beginning 12 years after the disaster,[86] with this increase beginning in Ukraine about 8 years later.[87] This effect is indicated despite smaller overall subject participation numbers in the FMU study (40% decrease since the program began), possibly due in part to pressure to opt out of FHMS thyroid screening[88].

Comparisons between the Chornobyl data sets (which differ even between the FSS) and Fukushima data should consider, in particular, the various exposure *rates*. For instance, the *health* data indicate that rates differed substantially between Belarus (high rates) and Ukraine and Russia (lower rates).

In addition, Toshihide Tsuda, an independent epidemiologist in Japan, found that "[a]n excess of thyroid cancer has been detected and is unlikely to be explained by a screening surge.[89]" This conclusion is supported by a study published very recently that linked external radiation doses

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[83] Tronko MD, Saenko VA, Shpak VM, Bogdanova TI, Suzuki S, Yamashita S. Age distribution of childhood thyroid cancer patients in Ukraine after Chernobyl and in Fukushima after the TEPCO-Fukushima Daiichi NPP accident. Thyroid. 2014;24(10):1547-1548. doi:10.1089/thy.2014.0198

[84] Takamura N, Orita M, Saenko V, Yamashita S, Nagataki S, Demidchik Y. Radiation and risk of thyroid cancer: Fukushima and Chernobyl. *Lancet Diabetes Endocrinol*. 2016;4(8):647. doi:10.1016/S2213-8587(16)30112-7 https://www.thelancet.com/journals/landia/article/PIIS2213-8587(16)30112-7/fulltext#gr1 Figure

[85] Kato, T, Yamada, K. Individual Dose Response and Radiation Origin of Childhood and Adolescent Thyroid Cancer in Fukushima, Japan. 2022. Clinical Oncology and Research. Volume 2022, pp 1-5; https://www.sciencerepository.org/articles/individual-dose-response-and-radiation_COR-2022-2-102.pdf

[86] Kato, T, Yamada, K. Individual Dose Response and Radiation Origin of Childhood and Adolescent Thyroid Cancer in Fukushima, Japan. 2022. Clinical Oncology and Research. Volume 2022, pp 1-5; https://www.sciencerepository.org/articles/individual-dose-response-and-radiation_COR-2022-2-102.pdf

[87] Sobolev, B., Likhtarev, I., Kairo, I., Tronko, N., Oleynik, V. and Bogdanova, T. Radiation risk assessment of the thyroid cancer in Ukrainian children exposed due to Chernobyl. 1996. Table 3 https://inis.iaea.org/collection/NCLCollectionStore/_Public/31/056/31056919.pdf

[88] Rosen, A.Thyroid cancer in Fukushima children increased 20-fold. Beyond Nuclear International. May 23, 2021. https://beyondnuclearinternational.org/2021/05/23/thyroid-cancer-in-fukushima-children-increased-20-fold/

[89] Tsuda T, Tokinobu A, Yamamoto E, Suzuki E. Thyroid Cancer Detection by Ultrasound Among Residents Ages 18 Years and Younger in Fukushima, Japan: 2011 to 2014. *Epidemiology*. 2016;27(3):316-322. doi:10.1097/EDE.0000000000000385

linearly to increases in thyroid cancers.[90] Coupled with these dose findings, thyroid cancer metastasis, aggressive growth and recurrence, it seems enhanced screenings are entirely appropriate as “a considerable proportion of thyroid cancers present as clinically relevant cases.”[91]

Reprocessing: the dirty end of the nuclear fuel chain

Reprocessing — the cutting up of irradiated reactor fuel rods in a chemical bath to extract plutonium and fissile uranium — involves the annual discharge of tens of millions of gallons of radioactively contaminated liquids and the release of radioactive gases such as krypton, xenon and carbon-14.[92]

A 1990 UK study of the Sellafield reprocessing facility by Martin J. Gardner et al[93] found higher incidences of leukaemia, particularly non-Hodgkin’s lymphoma, among children near the site. It concluded that this might be “associated with paternal employment and recorded external dose of whole body penetrating radiation during work at the plant before conception. The association can explain statistically the observed geographical excess. This result suggests an effect of ionising radiation on fathers that may be leukaemogenic in their offspring.”

There have been challenges to the Gardner hypothesis, but also challenges to those studies that contradict his paper. Gardner’s most notable opponent was the epidemiologist, Sir Richard Doll,[94] who testified on behalf of Sellafield owners, British Nuclear Fuels, Limited, in a 1994 court case won by BNFL challenging Gardner’s paternal occupational exposure conclusion.

Kinlen[95], since the early 1990s the lead proponent of population mixing and a viral cause, continues to uphold this theory, as do others, including Draper et al.,[96] who wrote that “These

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[90] Kato, T, Yamada, K. Individual Dose Response and Radiation Origin of Childhood and Adolescent Thyroid Cancer in Fukushima, Japan. 2022. Clinical Oncology and Research. Volume 2022, pp 1-5; https://www.sciencerepository.org/articles/individual-dose-response-and-radiation_COR-2022-2-102.pdf

[91] Drozd V, Saenko V, Branovan DI, Brown K, Yamashita S, Reiners C. A Search for Causes of Rising Incidence of Differentiated Thyroid Cancer in Children and Adolescents after Chernobyl and Fukushima: Comparison of the Clinical Features and Their Relevance for Treatment and Prognosis. Int J Environ Res Public Health. 2021 Mar 26;18(7):3444. doi: 10.3390/ijerph18073444. PMID: 33810323; PMCID: PMC8037740.

[92] Paviet-Hartmann P, Kerlin W, Bakhtiar S. Treatment of Gaseous Effluents Issued from Recyling – A Review of the Current Practices and Prospective Improvements. Idaho National Laboratory. November 2010.

[93] Gardner MJ, Snee MP, Hall AJ, Powell CA, Downes S, Terrell JD. Results of case-control study of leukaemia and lymphoma among young people near Sellafield nuclear plant in West Cumbria. BMJ. 1990 Feb 17;300(6722):423-9. doi: 10.1136/bmj.300.6722.423. Erratum in: BMJ. 1992 Sep 19;305(6855):715. PMID: 2107892; PMCID: PMC1662259.

[94] Doll R. The Seascale cluster: a probable explanation. Br J Cancer. 1999 Sep;81(1):3-5. doi: 10.1038/sj.bjc.6690642. PMID: 10487604; PMCID: PMC2374279.

[95] Kinlen LJ, Stiller C. Population mixing and excess of childhood leukemia. *BMJ*. 1993;306(6882):930. doi:10.1136/bmj.306.6882.930-a

results do not support the hypothesis that paternal preconception irradiation is a cause of childhood leukaemia and non-Hodgkin lymphoma; the observed associations may be chance findings or result from exposure to infective or other agents." Kinlen, however, concedes that a virus is "albeit not specifically identified."

However, other research has rejected the Kinlen hypothesis, including an investigation by Dickinson, HO et al.,[97] who conclude: "Children of radiation workers had a higher risk of leukaemia/non-Hodgkin's lymphoma than other children [rate ratio (RR) = 1.9, 95% confidence interval (CI) 1.0-3.1, p = 0.05]". The researchers used "a cohort rather than a case-control design, with wider temporal and geographic boundaries, and confirmed the statistical association between father's preconceptional irradiation and child's risk of leukaemia/non-Hodgkin's lymphoma," and concluded that "The possibility remains that paternal preconceptional irradiation may be a risk factor for leukaemia/non-Hodgkin's lymphoma, and this effect may not be confined to Seascale."

Law et al., publishing in 2003 in the American Journal of Epidemiology, also dismissed the population mixing hypothesis.[98] "Elevated risks of acute lymphoblastic leukaemia were found in areas with a low diversity of origins of migrants and for non-Hodgkin's lymphoma in areas with a low diversity of origins of child migrants; for other tumours, no covariates were associated," the authors wrote. "This study, and a survey of 17 published reports on population mixing, suggests that a low diversity of migrant backgrounds may be associated with acute lymphoblastic leukaemia.: Law concluded that "The findings from this investigation do not support the Kinlen population mixing hypothesis."

Furthermore, soil samples taken from around Sellafield, and analysed by Bremen University on behalf of Greenpeace, found 23 times the level of Americium-241 at Sellafield compared to the Chornobyl exclusion zone. This suggests that environmental exposure, rather than a virus, was a likely vector for leukaemias and other cancers, given the known harm caused by exposure to these radioactive isotopes.

A 1993 study[99] similarly found elevated rates of childhood leukaemia around the La Hague reprocessing site in France, leading to its lead author, Jean-François Viel, suffering vicious

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[96] Draper, GJ et al, Cancer in the offspring of radiation workers: a record linkage study, British Medical Journal, 8 November 1997, BMJ 1997;315:1181

[97] Dickinson HO, Parker L. Leukaemia and non-Hodgkin's lymphoma in children of male Sellafield radiation workers. Int J Cancer. 2002 May 20;99(3):437-44. doi: 10.1002/ijc.10385. PMID: 11992415.

[98] Graham R. Law, Roger C. Parslow, Eve Roman, on behalf of the United Kingdom Childhood Cancer Study Investigators, Childhood Cancer and Population Mixing, American Journal of Epidemiology, Volume 158, Issue 4, 15 August 2003, Pages 328–336, https://doi.org/10.1093/aje/kwg165

[99] Viel JF, Richardson S, Danel P, Boutard P, Malet M, Barrelier P, Reman O, Carré A. Childhood leukemia incidence in the vicinity of La Hague nuclear-waste reprocessing facility (France). Cancer Causes Control. 1993 Jul;4(4):341-3. doi: 10.1007/BF00051336. PMID: 8347783.

attacks in attempts to discredit his findings and reputation. These attacks worsened after the publication of a second paper the following year.[100]

The main by-product of nuclear power: radioactive waste

The selection of a deep geological repository — the option favoured by most nuclear countries for the management of irradiated reactor fuel — involves ethical as well as scientific challenges.

In the U.S., the selection of the now abandoned Yucca Mountain high-level radioactive waste repository site in Nevada violated the treaty rights of the Western Shoshone on whose tribal land it is located. It also ignored the inevitable contamination of groundwater sources beneath the mountain, which would subsequently harm tribal and agricultural populations downstream[101]

The Western Shoshone are particularly acutely attuned to the risks of radiation exposure, having lived downwind of the Nevada atomic test site, making them, as Ian Zabarte, Principle Man of the Western Bands of the Shoshone Nation of Indians, describes it, “the most bombed nation on Earth.” Further, in addition to the harm to health, Western Shoshone culture believes that “rocks, water, plants and animals matter as much as people do.” Western Shoshone elder, Pauline Esteves describes it this way: “I believe the land and everything that lives upon it are there to do good, not for radioactive materials.”

By mischaracterizing the Yucca Mountain site as a remote and uninhabited desert, the U.S. government discriminated against a culture and heritage stewarded by the Western Shoshone, whose experiences dealing with radioactive exposures, like those of other Indigenous and minority communities of colour, cannot be equated to the guidelines of Reference Man.

The US has now turned to “Consolidated Interim Storage” for the “temporary” accommodation of high-level radioactive reactor waste, identifying two largely Hispanic communities in Texas and New Mexico as host sites.[102] The approval process, which was not voluntary, has been challenged in court. However, given their increased sensitivity, any disposal of radioactive wastes in such parking lot-style facilities will put children in the host community at heightened risk of harm.

Elsewhere, the search for a radioactive waste management plan continues, with only Finland currently building a deep geologic repository. The question about harm to future generations remains unresolved, given the challenge of identifying the lethality of the repository contents to populations potentially a hundred thousand years or more into the future.

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[101] Tyler, Scott. Are Arid Regions Always that Appropriate for Waste Disposal? Examples of Complexity from Yucca Mountain, Nevada. Geosciences. January 2020.
[102] U.S. Nuclear Regulatory Commission. Consolidated Interim Storage Facility. NRC.gov

Conclusions

Despite the numerous observations globally linking radiation exposures to increased risks for children, pregnant, and non-pregnant women, and the well-demonstrated sensitivity to other toxicants during these life stages, exposure standards in the U.S. remain based on a Reference Man – a model that does not fully account for sex and age differences.

In addition, faulty research assumptions, unique exposure pathways, systemic inequities, and legacy exposures to both heavy metals and radioactivity from mining wastes, add to the risks for women and children, especially those in underserved communities. Socio-economic factors that drive higher deprivation of services in non-homegenous low income communities of colour also put non-White children at higher risk of negative health outcomes when exposed to radioactive releases, than their White counterparts.

A first and essential step is to acknowledge the connection between radiation, heavy metal and chemical exposures from industries and the negative health impacts observed among children, so that early diagnosis and treatment can be provided. Measures should then be taken to protect communities from further exposures, including a prompt phaseout of nuclear power and its supporting industries.

Studies are also urgently needed where there are none, and the findings of independent doctors, scientists and laboratories should be given equal attention and credence as those conducted by industry or government-controlled bodies, whose vested interests surely compromise both their methodologies and conclusions.

Finally, in the face of uncertainty, particularly at lower and chronic radiation doses, precaution is paramount. This means listening to, and taking seriously, the evidence provided by those living close to operating or closed nuclear facilities, rather than dismissing their fears by using faulty research assumptions and uncertainties in the science to deny health impacts and prevent protective and corrective actions.

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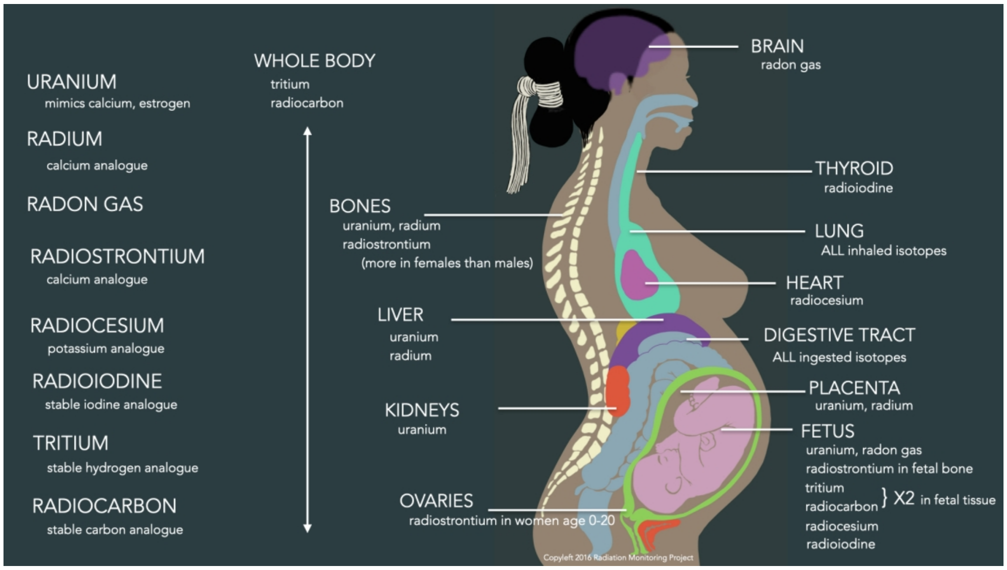

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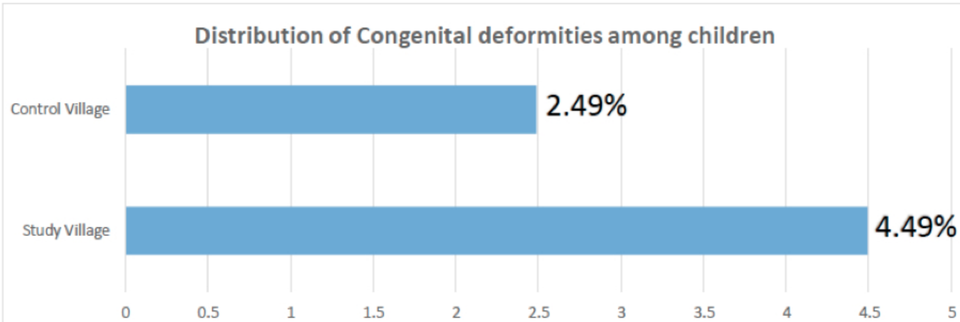

79x28mm (300 x 300 DPI)

4 European studies - post KiKK

Körblein A and Fairlie I. French Geocap study confirms increased leukemia risks in young children near nuclear power plants. Int J Cancer. Article published online: 1 Sept 2012. DOI: 10.1002/ijc.27585

Acute leukaemias in under 5s within 5 km of NPPs

Country	Observed	Expected	SIR=O/E	90%CI	p-value
Germany	34	24.1	1.41	1.04-1.88	0.0328
GB	20	15.4	1.30	0.86-1.89	0.1464
Suisse	11	7.9	1.40	0.78-2.31	0.1711
France	14	10.2	1.37	0.83-2.15	0.1506
pooled data	**79**	**57.5**	**1.37**	**1.13-1.66**	**0.0042**

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Radioactive releases from the nuclear power sector and implications for child health

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Radioactive releases from the nuclear power sector and implications for child health

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Key Points

1. Data on women, pregnant women, children and members of low-income and non-White communities, indicate that exposure to radioactivity may disproportionately harm the health of these demographics.
2. A nuclear accident releasing large amounts of radioactive isotopes can harm those immediately affected as well as future generations exposed to long-term low radiation doses.
3. Radiation exposure studies often discount the sensitivities of women, children and minorities or apply inappropriate models to assess the impacts.
4. Studies that focus on the more susceptible populations have recorded significant disproportionate harm to health compared to others in the population.
5. A number of prevailing faulty assumptions about data and research methods often prevent radiation studies from associating radiation exposure with disease increases, especially at low doses.

Abstract

Although radioactivity is released routinely at every stage of nuclear power generation, the regulation of these releases has never taken into account those potentially most sensitive — women, especially when pregnant, and children. From uranium mining and milling, to fuel manufacture, electricity generation and radioactive waste management, children in frontline and Indigenous communities can be disproportionately harmed due to often increased sensitivity of developing systems to toxic exposures, the lack of resources, and racial and class discrimination. The reasons for the greater susceptibility of women and children to harm from radiation exposure is not fully understood. Regulatory practices, particularly in the establishment of protective exposure standards, have failed to take this difference into account. Anecdotal evidence within communities around nuclear facilities suggests an association between radiation exposure and increases in birth defects, miscarriages and childhood cancers. A significant number of academic studies tend to ascribe causality to other factors related to diet and lifestyle and dismiss these health indicators as statistically insignificant. In the case of a major release of radiation due to a serious nuclear accident, children are again on the frontlines, with a noted susceptibility to thyroid cancer, which has been found in significant numbers among children exposed both by the 1986 Chornobyl nuclear accident in Ukraine and the 2011 Fukushima-Daiichi nuclear disaster in Japan. The response among authorities in Japan is to blame increased testing, or to reduce testing. More independent studies are needed focused on children, especially those in vulnerable frontline and Indigenous communities. In conducting such studies, greater consideration must be applied to culturally significant traditions and habits in these communities.

Introduction

Radioactivity is released at every stage of nuclear power production, from uranium mining to electricity generation to radioactive waste production. In some of these phases, toxic heavy metals are also released into the environment.

Children, women, and particularly pregnant women living near nuclear production facilities appear to be at disproportionately higher risk of harm from exposure to these releases. Children in poorer often Non-White and Indigenous communities with fewer resources and reduced access to health care are even more vulnerable — an impact compounded by discrimination, socio-economic and cultural factors.

Nevertheless, pregnancy, children and women are underprotected by current regulatory standards that are based on “allowable” or “permissible” doses for a “Reference Man”. Early in the nuclear weapons era, a “permissible dose” was more aptly recognized as an “acceptable injury limit,” but that language has since been sanitised.[i] Permissible does not mean safe. Reference Man is defined as “... a nuclear industry worker 20-30 years of age, [who] weighs 70 kg (154 pounds), is 170 cm (67 inches) tall...is a Caucasian and is a Western European or North American in habitat and custom.”[ii]

Very early research conducted in the United States in 1945 and 1946 indicated higher susceptibility of pregnancy to radiation exposure. Pregnant dogs injected with radiostrontium had defects in their offspring and yet, “complete results [of these studies] were not made public until 1969”.[iii]

By 1960 however, U.S. experts were clearly aware that research indicated higher susceptibility of children, when the Federal Radiation Council (FRC) (established in 1959 by President Eisenhower) briefly considered a definition for “Standard Child” – which they subsequently abandoned in favour of maintaining a Standard Man definition[iv] (later renamed Reference Man). The 1960 report also recognized hormones as a radiation “co-carcinogen”, which evokes later research indicating that radiation impacts the oestrogenic pathway, although the mechanism is not understood and has been poorly investigated[v].

And while the current U.S. Environmental Protection Agency (EPA) toxic exposure guidance recognizes an enhanced early lifecycle susceptibility to a number of mutagens[vi], recommending a risk factor increase of 10 after birth and before the age of two for some of these toxics[vii], radiation exposure standards are still based on Reference Man.

Differing impacts based on gender occur for a range of chemicals and various exposure scenarios. In some cases males are more susceptible than females, while the reverse is also seen.[viii] For ionizing radiation in particular, data from the survivors of the atomic bombings in Japan show “women from the same age-at-exposure cohort (26–30 years) suffered 50% more cancer…compared to the males”.[ix] The latest data from the atomic bombing survivor cohorts in Japan associate radiation exposure *in utero* with solid cancer mortality for adult females, but not males.[x]

Since female cumulative baseline rates for most cancer types are lower than male[xi], exposure to radiation may be erasing a woman's potential natural cancer resistance, while also increasing her risk relative to a man's. However, not enough research has been done in this area to be sure.

Current U.S. regulations allow a radiation dose to the public (100 mrem per year) which poses a lifetime cancer risk to the Reference Man model of 1 person in 143. This is despite the EPA's acceptable risk range for lifetime cancer risk from toxics being 1 person in 1 million to 1 person in 10,000.[xii] As noted by the EPA, this gives radiation a "privileged pollutant" status.[xiii] Additionally, biokinetic models for radioistopes are not sex-specific. A male model is still used for females. The models are also not fully age-dependent.[xiv] Radiation damage models also fail to account for a whole host of childhood and pregnancy damage.[xv]

There are known "windows of susceptibility" in a lifetime, "includ[ing] periods of active cell differentiation and growth in the womb and in early childhood as well as adolescence, when the brain is continuing to develop" during which "[c]hemicals can act like hormones and drugs to disrupt the control of development and function at very low doses…[i]n some cases, a susceptibility to disease also can persist long after the initial insult or exposure has ended".[xvi]

Women and children in underserved communities are at still greater risk because of unique exposure pathways, and systemic inequities. Traditional lifestyle and cultural patterns can also lead to increases in exposure. In the case of some Native Americans, exposure to toxics and radiation has been multi-generational, enduring over a period of 150 years.[xvii]

In an exploration of the studies, we find a notable lack of in-depth, independent research looking specifically at children, as well as the wider population in Indigenous or minority communities. Uncertainties caused by this lack of study are used by officials to underprotect those most at risk.

We also find a marked contrast between the conclusions of some of the studies and the anecdotal evidence on the ground.

Most of the primary research that *has* focused on the susceptibilities of women and children has consistently indicated disproportionate impacts, even among those possibly exposed to lower radiation doses. Impacts can include increases in childhood cancers, particularly leukaemia and central nervous system cancers,[xviii] neurological disorders, respiratory difficulties, cardiovascular dysfunction, immune dysfunction, perinatal mortality[xix] and birth defects.[xx,xxi] Rapid cell division is among the development processes thought to account for some of this susceptibility.

However, many studies are unable to link these adverse outcomes to radioactivity because the studies' authors tend to use several faulty assumptions:

1) "*doses will be too low to create an effect*" — a beginning assumption ensuring poor hypothesis formation and study design.[xxii] Therefore, when an effect is found,

radioactivity has been predetermined not to have an association with the effect. This exclusion often leads to an inability to find an alternate associated disease agent;

2) "*small negative findings matter*"— In fact, what matters are positive findings or very large negative findings;[xxiii]

3)"*statistical non-significance means a lack of association between radiation exposure and disease"* — a usage a number of scientists in various disciplines now call "ludicrous";[xxiv]

4) "*potential bias or confounding factors are reasons to dismiss low dose studies*" — In fact, when assessing low dose impacts, researchers should take care not to dismiss studies with these issues and researchers should minimise use of quality score ranking.[xxv]

Consequently, we examine and referenced studies even if they contained such faulty assumptions because they still indicated increases in certain diseases, such as some leukaemias, known to be caused by radiation exposure. Additionally, few alternative explanations were offered in the conclusions of these studies, meaning radiation exposure might still have been the cause.

Figure 1. Selected radioisotopes: where they travel and primarily collect in the body[xxvi]

Uranium mining and racial discrimination

Uranium mining contributes significantly to the wide dispersal of radioactive waste streams into the air, water and soil. Uranium mining also leaves behind a massive debris field of discarded radioactive residues, rocks and heavy metals, known as tailings.

Heavy metals are also released by uranium mining and these can be as toxic, if not more so, than the radioactive elements. The 1960 FRC report recognized radiation as a co-carcinogen with not only hormones but also viruses and chemicals, indicating synergistic impacts that have rarely been investigated. One study looking at medical impacts of the 1986 Chornobyl nuclear power plant disaster in Ukraine, found that multiple congenital malformations were much higher in areas of combined contamination, suggesting an additive and potentially synergistic effect between radioactive and chemical pollutants.[xxvii]

In the United States, Native American communities have constituted the majority of the uranium mining workforce. In the American Southwest, Navajo Nation community members have experienced increases in a number of diseases and lingering internal contamination from uranium mine waste among neonates and children. [xxviii],[xxix],[xxx],[xxxi] Native Americans also present with chronic ailments – such as kidney disease and hypertension – linked with living near and contact with uranium mine waste.[xxxii]

Additionally, comparing uranium mining health data from one race to another should be done with caution as “[t]he increased toxicity [of mining exposure] to Native miners underscores the potential for unique sensitivities to toxicants within the Native community as compared to all races results, questioning the derivation of standards on the basis of data collected from other populations.”[xxxiii]

It is also worth noting that some Native American communities are living with a 150-year health legacy of potential exposure to radioactive and heavy metal mine waste. Research on humans,[xxxiv] and additional studies on radioactivity and animals[xxxv],[xxxvi],[xxxvii] indicate that legacy exposures such as these result in a cumulative impact over generations and can leave descendants of a community more susceptible to damage from future exposures than their parents were.

An examination of Navajo babies born between 1964 and 1981 showed that congenital anomalies, developmental disorders, and other adverse birth outcomes were associated with the mother living near uranium mines and wastes.[xxxviii] The results of this study, published in 1992, were not followed up until 2010 with the establishment of the Navajo Birth Cohort study, a community-based and -driven initiative that examines the impact of chronic exposure to mine wastes on birth outcomes.[xxxix]

Historic and recent official research has, on the whole, been systemically racist by failing to account for culturally-specific exposure scenarios to Navajo. These include frequent contact with contaminated lands, waters and, in some cases, a nearly 100% reliance on locally grown and sourced foods[xl,xli], as well as failure to consider doses to Navajo Nation community members from the Trinity explosion—the first detonation of an atomic device.[xlii] Some research teams have attempted to address systemic racism by partnering with local community members and integrating local knowledge.[xliii]

In Jadugoda, India, where six uranium mines operate, the first opening in 1957, those affected are Indigenous peoples from the Santhal, Munda and Ho tribes. A local organisation, Jharkhandi Organisation Against Radiation, has been documenting strange health anomalies in the community for years, including deformities and birth defects.

Their observations were supported by an independent study[xliv] of the Jadugoda community conducted in 2007 by Indian Doctors for Peace and Development, which found that the offspring of mothers living near uranium mining operations area showed a significant increase in congenital deformities (4.49% vs 2.49%).[xlv]

As well as deformities, deaths were higher. Among mothers who lost their children after birth, 9.25% of mothers in the study villages reported congenital deformities as the cause of death of their children as compared to only 1.70% of mothers in the reference villages.[xlvi]

The authors concluded that the finding of the study confirms the hypotheses that the health of indigenous people around uranium mining is more vulnerable to certain health problems.[xlvii]

Figure 2. Congenital deformities among babies from mothers who lived near the Jadugoda uranium mining operations.

However, other studies contradict these conclusions. A 2013 study[xlviii], concluded that the water was safe for people to drink". And, a study[xlix] by scientists from India's Bhabha Atomic Research Centre, came to a similar conclusion. However, these studies are deficient in many ways, limiting their research to dose reconstruction rather than health outcomes and failing to consider inhalation or ingestion of radionuclides, other than from drinking water. Furthermore, the association with the Atomic Research Centre raises questions about conflict of interest.

People living in the town of Arlit in Niger, and those working in the huge majority French-owned uranium mine nearby, are exposed on a daily basis to levels of radioactivity higher than those found in the Chornobyl exclusion zone. Independent studies in Arlit[l], beginning in 2003, found radioactively contaminated metals discarded from the mine routinely used in households, where children were exposed.

An independent study commissioned by the European Parliament and published in 2010, looked at health and environmental legacy conditions around uranium mines in both Gabon and Niger and found, in the case of Niger, that waste dumps and related processing facilities posed a severe environmental and health hazard to the local population.[li] It also found evidence of radioactive contamination of local water supplies, and contaminated dust, and that contaminated construction materials had been sold in markets and used to build dwellings in local towns.[lii] However, despite observations of the risks from multiple scientific sources, there is a paucity of actual health studies. The health outcomes are largely recorded anecdotally, by activists on the ground such as the Arlit-based NGO, Aghirin' Man.[liii]

In Australia, uranium contaminates drinking water around uranium mine sites at rates far higher than recommended. Aboriginal communities, most likely to inhabit land around these facilities, suffer from increases in cancers and stillbirths according to the findings described below.

A 2019 Australian government study[liv] found increases in low birth weight, foetal death and cancers, but a "lack of evidence" that radiation was the cause, suggesting that alcohol and tobacco use, and a high-fat diet, could explain the increase in diseases. Radiation, which could have been a responsible agent, was eliminated because the researchers considered that the doses were too low to explain the remaining disease increases not attributable to non-radiation exposure factors. This was despite the known connection between radiation exposure and low birth weight and cancers. This conclusion left the community with unexplained disease increases, a pattern seen all too often in radiation health studies.

In her analysis, Rosalie Schultz states that "We owe it to Aboriginal people living near mines to understand and overcome what's making them sick",[lv] and further points out that *"*Development of the Ranger mine entailed nullification of veto rights, disempowering Aboriginal communities and threatening their livelihoods. With mining came royalty money, expensive commodities, money-hunger and alcohol".

These examples serve to highlight the tension between the often strong anecdotal evidence and the common failure to attribute the causal factor to a potential exposure source already linked to the outcome of interest in other populations.

Routine radioactive releases from nuclear power plants

Nuclear power plants routinely release radioactivity as part of daily operation. In 2008, a landmark case-control study was published in Germany[lvi], known as the KiKK study.

It revealed an unsettling 1.6-fold increase in all cancers and a 2.2-fold increase in leukaemias among children under five years old living within 5km of operating nuclear power plants.

In general, the incidences were higher the closer the children lived to the nuclear plant. The KiKK findings were backed up by other studies,[lvii] and a meta-analysis.[lviii]

However, the authors concluded that their findings were "unexplainable" because the doses were assumed to be too low to cause cancer. But UK radiation researcher, Dr. Ian Fairlie, hypothesises that sudden large spikes in radiation releases during reactor refuelling resulted in higher doses. These could account for higher rates of leukaemia among children.[lix]

Fairlie further posits that the observed high rates of infant leukaemias may be a teratogenic effect from radionuclides incorporated during pregnancy.[lx]

Other studies of natural and manmade background radiation associate childhood cancers with doses that are much lower than these spikes, but delivered continuously.[lxi] Taken together, these studies indicate that unique sensitivity to adverse effects of radiation exposure exists during pregnancy.

Table 1. Pooled analysis of leukaemias in children under 5 years of age within 5 km of nuclear reactors in Europe. Used with permission of Ian Fairlie***.***

Catastrophic radioactive waste releases

There have been at least three catastrophic releases of radioactivity from civilian nuclear reactors due to meltdowns: the 1979 Three Mile Island (TMI) disaster in the U.S.; the 1986 Chornobyl disaster in Ukraine; and the 2011 Fukushima, Japan nuclear disaster.

During the TMI crisis, there were 24 spontaneous abortions or stillbirths among pregnant women who were living within five miles of the nuclear facility and in their first four months of pregnancy. The expected number should be closer to twelve. The researchers of a study examining this, posit this may be due to stress (measured by number of evacuation days), but live births had equivalent evacuation days to abortions or stillbirths.[lxii]

Radiation from the TMI catastrophe was also associated with childhood leukaemia, although the study found only a small number of cases. Interestingly the study authors note an association with radiation exposure and all childhood cancers was also present before the catastrophe, albeit with wide confidence intervals. The authors recognize this increase, particularly leukaemia, as compatible with increases reported near some other nuclear installations, but eliminated radiation as a likely cause because the exposures were low.[lxiii] Yet, the authors cite seven additional studies that found this effect. An alternative explanation has yet to be revealed even as more recent studies have indicated increases of childhood leukaemias around operating nuclear facilities and in levels of higher background radiation (see above).

Outcomes in the Former Soviet States (FSS) from initial exposure to Chornobyl radioactive fallout include thyroid cancers (predominantly among those exposed during childhood) and significant increases in leukaemia among children who were in utero or who were under six years of age at the time of the Chornobyl catastrophe.[lxiv] Also found were increases in radiation-induced organic mental disorders.[lxv]

Among those continuing to live in Chornobyl-contaminated areas in the FSS, we see increases in cardiovascular disorders[lxvi],[lxvii] decreased lung function [lxviii],[lxix] defects of the lens of the eye [lxx], and significantly increased rates of conjoined twins, teratomas, neural tube defects, microcephaly, and microphthalmia.[lxxi] Further, research indicates significantly higher birth defects—some de novo— in the Chornobyl-contaminated Bryansk region. Projections indicate that certain birth defects will increase in the next few years.[lxxii]

The Chornobyl disaster produced a phenomenon known as "Chornobyl heart", where children were born with multiple heart defects – now being observed among children exposed as a result of the Fukushima catastrophe.[lxxiii] Some of these impacts occur at low, chronic doses.

Outside of the FSS, children born in regions of Sweden with higher Chornobyl fallout performed worse in secondary school – particularly in maths – and had more behavioural problems.[lxxiv] Similarly, in Norway, in utero exposure to Chornobyl radiation is associated with significantly lower verbal IQ, verbal working memory, and executive functioning.[lxxv],[lxxvi]

In Central Europe, studies observed a statistically significant increase in childhood leukaemias.[lxxvii] Perinatal mortality increased in European and FSS countries after the Chornobyl catastrophe,[lxxviii] and increases in trisomy 21 were found in Berlin and Belarus in 1987/1988. The cases coincided with exposure to Chornobyl fallout.[lxxix]

Perinatal mortality rates increased significantly in Fukushima and six neighbouring prefectures after the Fukushima nuclear disaster began, although researchers debate the magnitude of the increase and further study is needed to associate increases with radiation from the catastrophe.[lxxx],[lxxxi] After Fukushima, the International Commission on Radiological Protection made public its report encouraging the growing and eating of contaminated food to protect economic interests, while they also made recommendations for how much radiation people should be exposed to.[lxxxii] Yet their models do not fully account for being a child, female or pregnant.

Thyroid cancers among those exposed to Fukushima radiation as children have increased 20 times the expected rate, with about 80% metastasizing[lxxxiii] – indicating increased severity of the cancer and suggesting screening and surgery was necessary.

Despite this, SHAMISEN, a project funded by the European Commission, has recommended against systematic thyroid screening after nuclear catastrophes, claiming over-diagnosis and psychosocial impact can result.[lxxxiv]

Although it is correct that in some countries apparently high levels of undiagnosed thyroid anomalies exist without clinical symptoms, banning thyroid screening altogether after nuclear disasters such as Fukushima denies those exposed the essential medical treatment that could catch aggressive cancers early.

The suggestion that medical examinations are psychologically scarring[lxxxv] has sometimes been proffered as a justification for avoiding looking for health impacts from radiation exposure after a nuclear accident. Fewer tests have led to fewer findings in some of the more recent studies.

Some advocates of reduced screening point to studies from South Korea that blame an "epidemic" of thyroid cancers on increased screening. But data from Japan should not be compared to data from the South Korean study because the latter study *excluded* participants younger than 20 years, with only 2% in the 20-29 age range.[lxxxvi] Conversely, the Fukushima health management survey (FHMS), is examining those who were under 18 years of age at exposure.[lxxxvii]

Researchers also claim that any increasing thyroid cancer incidence rates in Japan are not due to radiation exposure because the age pattern of thyroid cancers arising in Japan after Fukushima differs from that arising after Chornobyl in the former USSR countries.[lxxxviii]

Five years after the Chornobyl disaster began, Belarus data indeed show a large increase in thyroid cancer diagnoses in those aged 0-4 at time of exposure[lxxxix] (AE), unlike the Fukushima data. However, the pattern[xc] in Ukraine and Russia *is* similar to the Fukushima data, which show increasing disease among younger age groups as more years pass. Ukraine and Russia, as with the Fukushima data, only demonstrated a high thyroid cancer incidence in age group 0-4 AE beginning 12 years after the disaster,[xci] with this increase beginning in Ukraine about 8 years later.[xcii] This effect is indicated despite smaller overall subject participation numbers in the FMU study (40% decrease since the program began), possibly due in part to pressure to opt out of FHMS thyroid screening.[xciii]

Comparisons between the Chornobyl data sets (which differ even between the FSS) and Fukushima data should consider, in particular, the various exposure *rates*. For instance, the *health* data indicate that rates differed substantially between Belarus (high rates) and Ukraine and Russia (lower rates).

In addition, research found an excess of thyroid cancer that is unlikely to be explained by an increase in screening.[xciv] This conclusion is supported by a study published very recently that linked external radiation doses linearly to increases in thyroid cancers.[xcv] Coupled with these dose findings, thyroid cancer metastasis, aggressive growth and recurrence, it seems enhanced screenings are entirely appropriate as many of these cancers are clinically relevant.[xcvi]

Reprocessing: the dirty end of the nuclear fuel chain

Reprocessing — the cutting up of irradiated reactor fuel rods in a chemical bath to extract plutonium and fissile uranium — involves the annual discharge of tens of millions of gallons of radioactively contaminated liquids and the release of radioactive gases such as krypton, xenon and carbon-14.[xcvii]

A 1990 UK study of the Sellafield reprocessing facility [xcviii] found higher incidences of leukaemia, particularly non-Hodgkin's lymphoma, among children near the site. It concluded that this might be associated with the fathers working at the plant and external doses of whole body penetrating radiation before conception. This would explain statistically the observed geographical excess. The study suggested that one effect of ionising radiation on the fathers could in turn be leukaemogenic in their offspring.

There have been challenges to this hypothesis, but also challenges to those studies that contradict his paper. Gardner's most notable opponent was the epidemiologist, Sir Richard Doll,[xcix] who testified on behalf of Sellafield owners, British Nuclear Fuels, Limited, in a 1994 court case won by BNFL challenging Gardner's paternal occupational exposure conclusion.

Kinlen[c], since the early 1990s the lead proponent of population mixing and a viral cause, continues to uphold this theory, as do others, including Draper et al.,[ci] who viewed the observed associations as potentially chance findings or possibly other infectious sources. Kinlen, however, concedes that such a virus has not been specifically identified.

Other research has rejected the Kinlen hypothesis, including an investigation by Dickinson, HO et al.,[cii] who concluded that "Children of radiation workers had a higher risk of leukaemia/non-Hodgkin's lymphoma than other children [rate ratio (RR) = 1.9, 95% confidence interval (CI) 1.0-3.1, p = 0.05]". The researchers used a cohort rather than a case-control design, with wider temporal and geographic boundaries, and confirmed the statistical association between father's preconceptional irradiation and child's risk of leukaemia/non-Hodgkin's lymphoma, and concluded that paternal preconceptional irradiation could be a possible risk factor for leukaemia and/ior non-Hodgkin's lymphoma, and that such outcomes might be found beyond the local worker town of Seascale.

Law et al., also dismissed the population mixing hypothesis.[ciii] His work discovered increased risks of acute lymphoblastic leukaemias in areas with few outsiders or migrants, as well as for non-Hodgkin's lymphoma in areas with low numbers of child migrants. Law concluded that his findings therefore do not support the Kinlen population mixing hypothesis.

A 1993 study[civ] similarly found elevated rates of childhood leukaemia around the La Hague reprocessing site in France, a second paper the following year had similar findings.[cv]

The main by-product of nuclear power: radioactive waste

The selection of a deep geological repository — the option favoured by most nuclear countries for the management of irradiated reactor fuel — involves ethical as well as scientific challenges.

In the U.S., the selection of the now abandoned Yucca Mountain high-level radioactive waste repository site in Nevada violated the treaty rights of the Western Shoshone on whose tribal land it is located. It also ignored the inevitable contamination of groundwater sources beneath the mountain, which would subsequently harm tribal and agricultural populations downstream.[cvi]

The Western Shoshone are particularly acutely attuned to the risks of radiation exposure, having lived downwind of the Nevada atomic test site, making them, as Ian Zabarte, Principle Man of the Western Bands of the Shoshone Nation of Indians, describes it, "the most bombed nation on Earth." Further, in addition to the harm to health, Western Shoshone culture believes that "rocks, water, plants and animals matter as much as people do." Western Shoshone elder, Pauline Esteves describes it this way: "I believe the land and everything that lives upon it are there to do good, not for radioactive materials."

By mischaracterizing the Yucca Mountain site as a remote and uninhabited desert, the U.S. government discriminated against a culture and heritage stewarded by the Western Shoshone, whose experiences dealing with radioactive exposures, like those of other Indigenous and minority communities of colour, cannot be equated to the guidelines of Reference Man.

The US has now turned to "Consolidated Interim Storage" for the "temporary" accommodation of high-level radioactive reactor waste, identifying two largely Hispanic communities in Texas and New Mexico as host sites.[cvii] The approval process, which was not voluntary, has been challenged in court. However, given their increased sensitivity, any disposal of radioactive wastes in such parking lot-style facilities will put children in the host community at heightened risk of harm.

Elsewhere, the search for a radioactive waste management plan continues, with only Finland currently building a deep geologic repository. The question about harm to future generations remains unresolved, given the challenge of identifying the lethality of the repository contents to populations potentially a hundred thousand years or more into the future.

Conclusions

Despite the numerous observations globally, linking radiation exposures to increased risks for children, pregnant, and non-pregnant women, and the well-demonstrated sensitivity to other toxicants during these life stages, exposure standards in the U.S. remain based on a Reference Man – a model that does not fully account for sex and age differences.

In addition, faulty research assumptions, unique exposure pathways, systemic inequities, and legacy exposures to both heavy metals and radioactivity from mining wastes, add to the risks for women and children, especially those in underserved communities. Socio-economic factors that drive higher deprivation of services in non-homegenous low income communities of colour also put non-White children at higher risk of negative health outcomes when exposed to radioactive releases, than their White counterparts.

A first and essential step is to acknowledge the connection between radiation, heavy metal and chemical exposures from industries and the negative health impacts observed among children, so that early diagnosis and treatment can be provided. Measures should then be taken to protect communities from further exposures, including a prompt phaseout of nuclear power and its supporting industries.

Studies are also urgently needed where there are none, and the findings of independent doctors, scientists and laboratories should be given equal attention and credence as those conducted by industry or government-controlled bodies, whose vested interests surely compromise both their methodologies and conclusions.

Finally, in the face of uncertainty, particularly at lower and chronic radiation doses, precaution is paramount. This means listening to, and taking seriously, the evidence provided by those living close to operating or closed nuclear facilities, rather than dismissing their fears by using faulty research assumptions and uncertainties in the science to deny health impacts and prevent protective and corrective actions.

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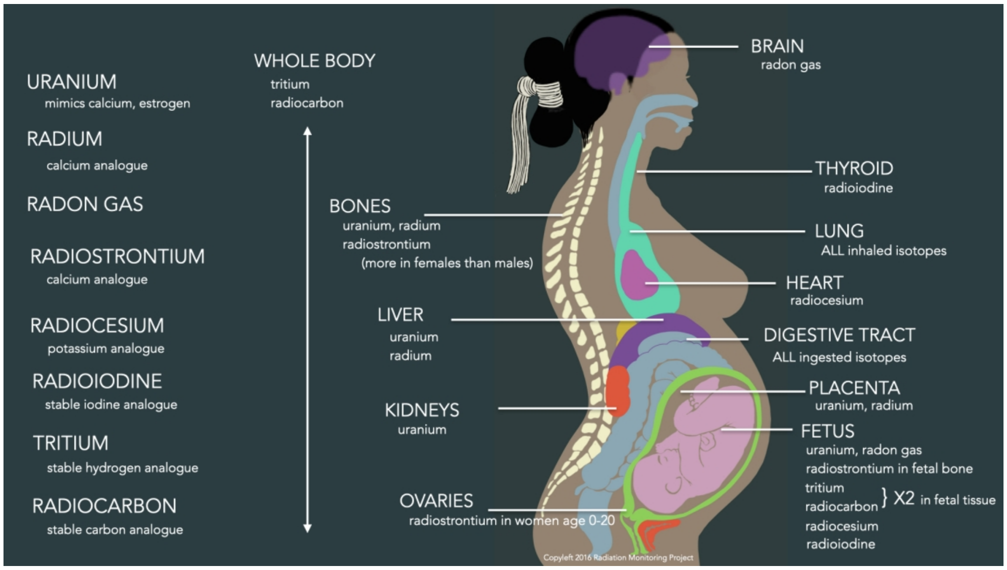

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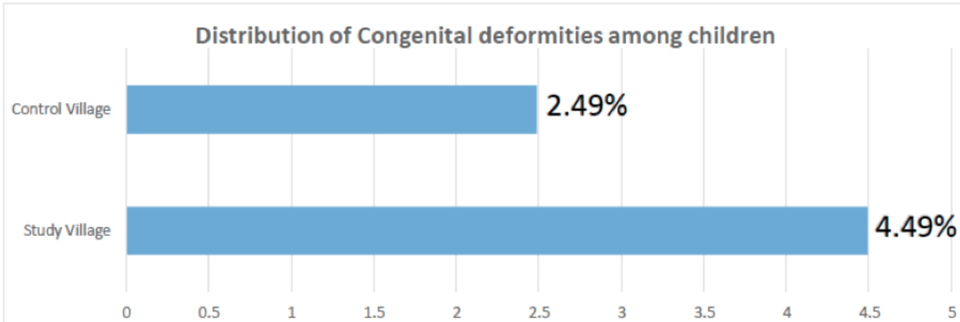

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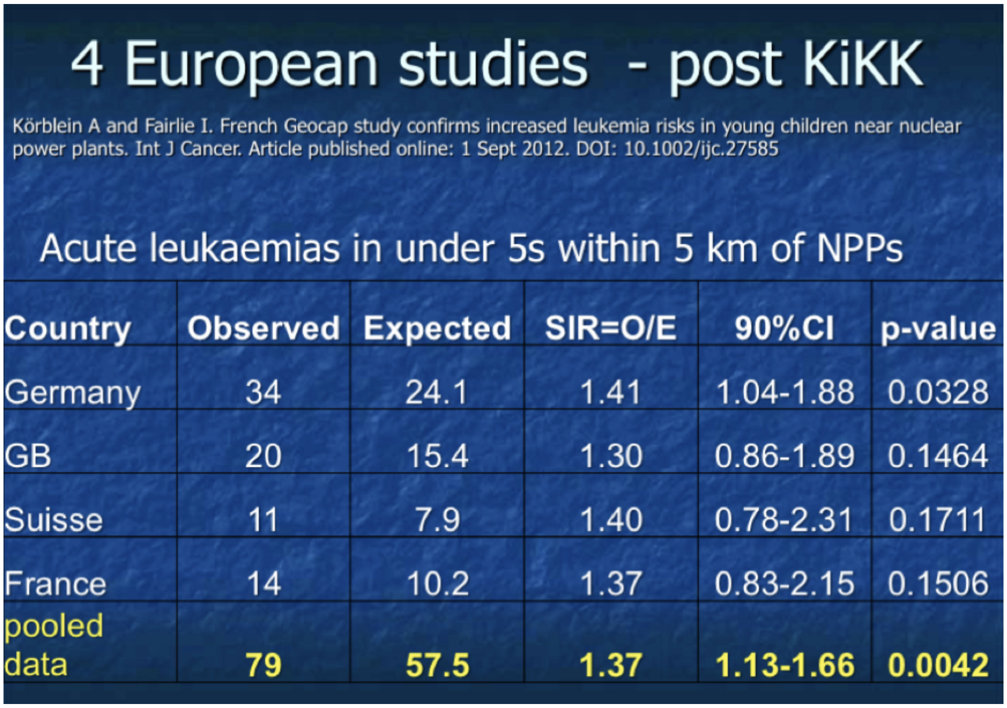
4 European studies - post KiKK

Körblein A and Fairlie I. French Geocap study confirms increased leukemia risks in young children near nuclear power plants. Int J Cancer. Article published online: 1 Sept 2012. DOI: 10.1002/ijc.27585

Acute leukaemias in under 5s within 5 km of NPPs

Country	Observed	Expected	SIR=O/E	90%CI	p-value
Germany	34	24.1	1.41	1.04-1.88	0.0328
GB	20	15.4	1.30	0.86-1.89	0.1464
Suisse	11	7.9	1.40	0.78-2.31	0.1711
France	14	10.2	1.37	0.83-2.15	0.1506
pooled data	**79**	**57.5**	**1.37**	**1.13-1.66**	**0.0042**

79x55mm (300 x 300 DPI)