Radiation Health Effects

Joint Project Factsheet

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Health consequences are a key issue for nuclear energy. Health effects, especially of low-level radiation, are often difficult to prove scientifically, which leads to disagreements of members of pro and anti-nuclear communities and scientists that are still ongoing in 2016, the year of the 30th anniversary of the Chernobyl accident and the 5th of Fukushima.

For the Joint Project factsheet up-to-date epidemiological studies and publications on health effects of low-level radiation have been collected and assessed for informing the public and supporting NGOs in anti-nuclear work.

Introduction

Radiation effects human health. While radiation sickness is a known consequence of high-level radiation, health effects of low-level radiation are one of the most disputed topics in medical science. Low-level radiation results from nuclear installations during normal operation and accident situations for workers and the public. Also the contamination from nuclear bombs (Hiroshima and Nagasaki) and atmospheric nuclear weapons testing[1] can still be measured – large parts of the northern hemisphere are contaminated with radionuclides like Cesium-137, Strontium-90 and Plutonium.

Why are health effects of low-level radiation so highly controversial and why is critical epidemiological research often not acknowledged properly in the nuclear community? Among other things, this is due to methods. Especially after Chernobyl when very large population groups were contaminated it was difficult to get valid and complete data, partly due to lack of monitoring systems, unreliable medical systems and political unwillingness. Besides lacking data, health effects of low-level radiation are not easy to detect. Diseases are normally caused by a variety of agents (like environmental toxins, smoking or bad lifestyle), and it is not easy to prove the cause of illness – especially when the investigated population group is small or data are incomplete.

In the last years, radiation effects on workers in nuclear facilities have been studied extensively. Here the data base is better. A big study (INWORKS) has been conducted recently proving adverse health effects of low-level radiation that can no longer be ignored. Also studies on the effects of natural radiation help to bring clarity into the debate.

In this factsheet new epidemiological work on health effects of low-level radiation is discussed with the aim of showing how the most important health effects can be verified by now – thirty years after Chernobyl and five years after Fukushima.

A glossary helps to understand epidemiological terms and concepts.

[1] Over 2000 nuclear tests were carried out between 1945 and 1996. (https://www.ctbto.org/)

Glossary

Case-control study	The second best type of epidemiological study, of the type analytical study. Each case (a person with the disease) is compared to a comparable person without disease (control-person). It is analyzed if the exposure has been different. Results are given as odds ratios (OR).
CI	Confidence interval: statistical value.
Cohort study	Cohort studies are the most reliable epidemiological studies, of the type analytical study. A cohort is a defined group of people who have been exposed, and their developing a disease over time is compared to a so-called control-group, which is another cohort who has not been exposed. A cohort study starts before the analyzed disease occurs for the first time. Cohort and control-group should be comparable except for the exposure. Results are given as relative risk (RR or ERR).
Ecological study	The third-best type of epidemiological study, of the type descriptive study. They are not based on individual but on collective dose-response-relationships. Results are given in amount of persons having the disease per 100,000 persons in the district.
ERR	Excess relative risk: this is another form to express the result of a cohort study: for RR 1.2 the ERR = 20%, it describes the excess risk of the exposed cohort in comparison to the unexposed cohort
Gray, Gy	Unit of absorbed radiation, defined as the absorption of one joule of radiation energy per kilogram of matter
Incidence ratio	Also called absolute risk, cumulative incidence; number of new cases of the disease per year and 100,000 people
Nested case-control study	This is a variation of a case-control study in which only a subset of controls from the cohort are compared to the incident cases. The nested case control model is generally more efficient than a case-cohort design.
OR	Odds ratio; OR is the ratio of the chance (not the probability) for the exposed person (case) to get a disease in comparison to the unexposed person (control-case). Only for rare diseases (like leukemia), OR is about the same as RR. If OR =1, both persons have the same chance to get the disease, OR =2 means that the exposed person has a two-fold chance to get the disease compared to the non-exposed person.
Prevalence	Proportion of population with disease
RR	Relative risk or risk ratio; RR is the ratio of the probability of occurrence of a disease among exposed people to that among the unexposed. RR is the result of a cohort study. Example: RR = 1 means that the risk for the disease does not depend on exposure. RR =2 means that the exposed cohort will twice as likely get the disease than the non-exposed group. RR = 0.1 means that the exposure is very good for you…
Standardization	Real life groups of people (f.e. inhabitants of different districts) are not comparable as such due to different age structures. For such groups it can be calculated how many cases of a disease would occur if the groups would be similar in age-structure, this is called age standardization or age adjustment.
Sievert, Sv	Unit of radiation dose; it is calculated by multiplying the absorbed radiation (Gray) with a quality factor

Thyroid cancer

Radioactive iodine is one of the first radionuclides released by a nuclear accident. If inhaled or ingested it will accumulate in the thyroid gland and increase the risk of getting thyroid cancer.

An increase in thyroid cancer became evident quite soon after **Chernobyl** in parts of Ukraine and Belarus. Even if pro-nuclear organizations like the IAEA tried to downplay this health effect, the increases became too obvious. In the UNSCEAR Scientific Annex for Chernobyl effects (UNSCEAR 2011, p. 148) an overview of epidemiological studies is given. Cohort studies and case-control-studies show excess relative risk (ERR) of 1.65 to 48.7, ecological studies of 4.4 to 67.8. Women are more at risk than men. Increases have not stopped by now.

In 2015, the first study about thyroid cancer after **Fukushima** was published (Tsuda et al. 2016). After the accident, the Fukushima Prefecture performed ultrasound thyroid screening on all residents ages ≤18 years. The first round of screening included 298,577 examinees, and a second round began in April 2014. Tsuda et al. analyzed the prefecture results from the first and second round up to December 31, 2014, in comparison with the Japanese annual incidence and the incidence within a reference area in Fukushima Prefecture. As a result they observed the highest incidence rate ratio, using a latency period of 4 years, in the central middle district of the prefecture compared with the Japanese annual incidence (incidence rate ratio = 50; 95% CI = 25, 90). The prevalence of thyroid cancer was 605 per million examinees (95% CI = 302, 1,082) and the prevalence odds ratio compared with the reference district in Fukushima Prefecture was 2.6 (95% CI = 0.99, 7.0). In the second screening round, even under the assumption that the rest of examinees were disease free, an incidence rate ratio of 12 has already been observed (95% CI = 5.1, 23). As conclusion it can be said that an excess of thyroid cancer has been detected among children and adolescents in Fukushima Prefecture within four years of the release, and is unlikely to be explained by a screening surge.

Leukemia and lymphomas

Leukemia is the umbrella term for different types of cancers of the bone marrow. There are chronic and acute types. The four common types are Chronic Lymphoblastic Leukemia (CLL), Chronic Myeloid Leukemia (CML), Acute Lymphoblastic Leukemia (ALL) and Acute Myeloid Leukemia (AML). Children's leukemia is mostly of the acute type. *Lymphomas* are blood cell tumors developed from lymphocytes. They can be cancerous. Types are Hodgkin and non-Hodgkin Lymphomas. The World Health Organization WHO distinguishes between multiple myeloma and immunoproliferative diseases. It is well known that leukemia can be caused be high radiation doses (based on analyzing the Japanese bomb survivors), but the effects of low doses are still disputed. Also it was believed that CLL is not radiation induced. New studies show that also low, protracted doses increase the risk of leukemia, and that CLL can also be radiation induced.

Risks of most types of leukemia from exposure to acute high doses of ionizing radiation are well known, but risks associated with protracted exposures, as well as associations between radiation and *chronic lymphocytic leukemia (CLL)*, are not clear. Therefore, a nested case-control study among a cohort of 110,645 *male Ukrainian cleanup workers* after the **Chernobyl** accident was undertaken. (Zablotska et al. 2013) Analyzed were all cases of leukemia that have been diagnosed between 1986 and 2006. The controls were matched by age and place of birth. Individual radiation doses were estimated for the bone marrow. For CLL, the ERR/Gy was 2.58 (95% CI: 0.02, 8.43), and for non-CLL, ERR/Gy was 2.21 (95% CI: 0.05, 7.61). Altogether, 16% of leukemia cases (18% of CLL, 15% of non-

CLL) were attributed to radiation exposure. Based on this primary analysis, the study concluded that both CLL and non-CLL are radiosensitive. Using the age-specific incidence rate of CLL among men in Ukraine for 2003, it was estimated that the number of CLL cases diagnosed in the analyzed cohort over the period of 20 years after the accident was 60% higher than what would be expected for the general male population of Ukraine.

Another case-control study was conducted among *children aged 0-5 years* in the Ukraine's mostly contaminated regions. (Noshechenko et al. 2015) The aim of the study was to analyze their risk of *acute leukemia* during the period from 1987 to 1997. Four dose-range groups were selected for statistical analysis (0–2.9, 3–9.9, 10–99.9 and 100–313.3 mGy). The risk of leukemia was significantly increased (–2.4 [95%CI: 1.4–4.0]) among those with radiation exposure doses higher than 10 mGy (p 5 0.01). The risk was increased particularly for acute myeloid leukemia.

A Japanese online media platform published on Aug 20th, 2016 that already two workers who developed leukemia after clean-up in **Fukushima** were entitled to workers compensations. (The Asahi Shimbun 2016) The first man received a dose of about 16 mSv, the second man about 54.4 mSv. Additional applications for compensations are expected.

The **International Nuclear WORKers** Study (INWORKS) analyzed effects of low, protracted or intermittent doses on cancer mortality. One of the publications of the INWORKS team shows new insights into mortality by leukemia and lymphoma. (Leuraud et al. 2015) In this study, 308,297 nuclear workers from three different countries (France, USA and UK) were included in an international cohort study. The workers have been monitored for external exposure to radiation with personal dosimeters and followed up for up to 60 years after exposure. The association between their bone marrow doses and mortality due to leukemia and lymphoma was studied. The ERR of leukemia mortality (without CLL) was 2.96 per Gy (90% CI 1·17–5·21; lagged 2 years), mostly tributed by chronic myeloid leukemia. As the authors state, this study provides strong evidence of positive associations between protracted low-dose radiation exposure and leukemia.

A Swiss study investigated **childhood leukemia and lymphoma caused by natural background radiation** from terrestrial gamma and cosmic rays. (Spycher 2015) A nationwide census-based cohort study was conducted for children < 16 years in 1990 and 2000, with follow-up until 2008. On average, natural terrestrial radiation contributed 54 nSv/h, cosmic radiation 45 nSv/h and artificial terrestrial radiation 8 nSV/h. The study found evidence of an increased risk of cancer among children exposed to external dose rates of background ionizing radiation of ≥200 nSv/h compared to those exposed to <100 nSv/h. The increased risk among children exposed to a dose rates ≥200 nSv/h compared to those exposed to <100nSv/h for leukemia was HR = 2.04 (95% CI: 1.11, 3.74).

Breast cancer and other solid cancers

Cancer is a known radiation health effect. Besides thyroid cancer and leukemia which are discussed above, breast cancer is a leading cause for death of women. Because of a longer latency period there are no data for breast cancer caused by Fukushima available by now.

Cardis et al. (2006) published a review of knowledge about breast cancer after **Chernobyl**. They concluded that several studies showed increases but lacked information about dose levels. This gap was closed by an ecological study investigating doses and increases in breast cancer in Belarus and Ukraine in age-cohorts in differently contaminated regions. (Pukkala et al. 2006) A significant 2-fold increase in risk was observed, during the period 1997–2001, in the most contaminated districts (average cumulative dose of 40.0 mSv or more) compared with the least contaminated districts (relative risk [RR] in Belarus 2.24 (95% CI] 1.51–3.32) and in Ukraine 1.78 (95% CI 5 1.08–2.93). The increase, though based on a relatively small number of cases, appeared approximately 10 years after the accident, was highest among women who were younger at the time of the accident.

These results are supported by a case-control study among young Ukrainian women exposed by Chernobyl. (Khyrunenko et al. 2011) Women investigated were aged -9 month (in utero) to 18 years at the time of accident. For each case and control living in contaminated territories the individual accumulated dose of irradiation was estimated. The odds ratios calculated from the case-control comparisons are indicative of a relationship between radiation dose and the development of breast cancer.

A descriptive epidemiological study of clean-up workers from Ukraine, evacuees from the 30km zone and residents of the most contaminated areas of the Ukraine was carried out. (Prysyazhnyuk et al. 2014) Significant excess for breast cancer was revealed among female clean-up workers.

The question if breast cancer can also result from **normal operation of NPPs** was investigated by C. Busby. (Busby 2015) He examined the risk of dying of breast cancer between 1995 and 2001 in wards adjoining the estuary of the River Blackwater in Essex, UK where measured radionuclide contamination exists in muddy sediment and other material, derived from discharges from the Bradwell Nuclear Power station. Results showed a significant effect with relative risk for the River Blackwater Estuary vs. other wards with Relative Risk RR = 1.7 (CI 1.22, 2.34; p = 0.0015). Comparison with a non-contaminated ward showed also RR = 2.1 (CI 1.12, 3.98; p = 0.018).

Other solid cancers

The above introduced INWORKs study investigated not only leukemia, but also other cancer mortality among the cohort of 308,297 **nuclear workers.** (Richardson et al. 2015) Results suggest a linear increase in the rate of cancer with increasing radiation exposure. The estimated rate of mortality from all cancers excluding leukaemia increased with cumulative dose by 48% per Gy (90% CI 20% to 79%), lagged by 10 years. The study provides a direct estimate of the association between protracted low dose exposure to ionizing radiation and solid cancer mortality. Although high dose rate exposures are thought to be more dangerous than low dose rate exposures, the risk per unit of radiation dose for cancer among radiation workers was similar to estimates derived from studies of Japanese atomic bomb survivors.

Genetic and teratogenic effects

Especially genetic and teratogenic effects of radiation are disputed to a high degree. Schmitz-Feuerhake, Busby and Pflugbeil published very recently a paper in which they list arguments for a new assessment. (Schmitz-Feuerhake et al. 2016) They criticize UNSCEAR and ICRP for their very low risk factors for hereditary diseases in humans based on reportedly absent genetic effects in the acute exposed Japanese A-bomb survivors. Schmitz-Feuerhake et al. made a compilation of findings about early deaths, congenital malformations, Down´s syndrome, cancer and other genetic effects observed in humans after the exposure of parents who were contaminated by Chernobyl fallout, parents who were clean-up workers and nuclear test veterans. Nearly all types of hereditary defects were found at very low doses. The authors suggest that the results show that current radiation risk models fail to predict or explain the many observations and should be abandoned.

Also Körblein states that the ICRP threshold dose of 100 mSv of teratogenic effects has to be given up. (Körblein 2011) He argues that the mortality rate of newborn (perinatal mortality) was increased in Germany in 1987, the year after Chernobyl, compared with the trend of the years 1980-1993. Also in Poland and other Eastern countries, significant peaks of perinatal mortality and stillbirths were found in 1987.

Conclusions

In earlier studies the effects of low dose radiation have already been investigated, but newer studies can provide better information on radiation effects. The effects of low, protected doses have been found to be similar to those of higher doses.

Although there are numerous studies in the area of assessment of impacts of nuclear power plants on human health, it is still necessary to make follow-ups, especially to investigate radiation effects of normal operation of nuclear facilities in depth. Particularly in countries where the nuclear lobby is in a very powerful position, it is necessary to try to arrange independent studies or independent reviews of existing studies.

It is of uttermost importance that new insights in radiation effects will be considered in radiation protection law and measures.

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