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Environmental Health Surveillance for Health Risk Assessment Following Radionuclide Release

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Abstract

The currently established linear nontreshold (LNT) risk model is used for radiation protection and is actually not intended for risk assessment. Also dose concepts such as effective dose are constructions used for radiation protection, focusing on the regulatory use in standards for workers but is seldom useful for members of the public. Both the LNT model, as well as use of the concept effective dose, are also not applicable in the low dose area. An alternative method for public health risk assessment and disease surveillance can be the combination of environmental radiation monitoring and health databases. For example, after the Chernobyl accident, airborne measurements of cesium-137 gamma spectrum from the ground, activity data from food samples and high quality national health registries were used for the risk assessment of cancer development.

Keywords: cancer, health surveillance, ionizing radiation, nuclear accident, risk assessment

1. Introduction

The golden standard for risk assessment of health effects from ionizing radiation are mortality data from the LSS (Life Span Study) cohort of survivors after the atomic bombings in Hiroshima and Nagasaki in 1945. Based on epidemiological data from the 93,000 survivors, the currently accepted linear nontreshold (LNT) risk model has been established. There are however several important shortcomings of this model. Firstly the LSS cohort is mainly based on mortality data. It is well-known that mortality data is inexact in diagnostic criteria, mostly lacking autopsy data. Cancer registries for cancer incidence data using histologically verified sampling have better diagnostic accuracy. Secondly the LSS cohort is based on acute exposure at the time of the bombing, but very little chronic exposure due to local fallout.

Most radioactivity was spread in the atmosphere after the bombings giving relatively little local fallout. Thirdly the LNT model is poorly verified in the so called low dose region (<100 mGy/mSv). A recent follow-up of the LSS-cohort after 52 years point at uncertainties of the shape of the dose response curve supporting a linear-quadratic model [1]. Perhaps the most debated detail about the LNT model is the introduction of a risk reduction for the low dose region. The so called “dose and dose-rate effectiveness factor”, DDREF, suggest that the risk of malignancy should be lowered by a factor of 2 in the low dose region (<100 mSv) introduced by the International Commission on Radiological Protection (ICRP). The theoretical argument for this arbitrary halving of risk estimates was that cellular repair mechanisms ought to be more efficient at low doses and low dose-rates. Perhaps a corrected radiation risk model will be considered in the light of new data and based on both physical, epidemiological and biologic data. Most other biological, medical and toxicological systems have exponential or s-shaped relationships between exposure and outcome, instead of linear. Models for radiation protection are also made mainly for regulatory purposes and do not directly reflect risk of disease, especially for exposures to populations in the low dose region. Therefore, nuclear accidents, such as in Harrisburg, Chernobyl or Fukushima, differ substantially from the conditions on which the LSS cohort and the LNT model are based. Other approaches using national health databases and environmental monitoring to detect health risks might be useful.

2. Assessment of dose

2.1. Uncertainties in dose measurements

The currently used dose estimates, such as equivalent dose or effective dose, are constructions used for radiation protection, focusing on the regulatory use in standards for workers but are seldom useful for members of the public. These dose estimates make use of several weighing factor, depending on type of radiation and the organ affected.

However, environmental exposure are often complex, including multiple tissues or whole body exposure. It is also often a combination of both external and internal exposure. For that purpose the International Commission on Radiological Protection (ICRP) recommends a weighing factor for effective dose, specific for 14 different organ/tissue categories. This weighing factor is based on years of life lost and also genetic effects, rather than the biological risk of cancer development. As a consequence thyroid cancer is weighed one third of bone marrow malignancy, breast cancer and stomach cancer, which is not related to the biological risk of developing a malignancy from a certain radiation dose.

The currently used dose estimates are primarily not constructed to be used in epidemiological studies on cancer incidence, since the weighing factors are evaluating the severity of health outcomes, mortality and even genetic effects. Therefore a discussion should be introduced about what dose risk estimates might be more suitable for epidemiological studies of cancer incidence, for example using absorbed dose energy with both radiophysically and biologically based correction factors.

2.2. Alternative biological dosimetry techniques

There are no biological markers for the assessment of low dose or low dose-rate exposures to humans [2]. After receiving larger external doses, nail and tooth enamel magnetic resonance analysis might be used, though with a large inaccuracy of dosimetry of 30–50 mGy, high costs and advanced laboratory equipment limiting the practical use [3]. Examples of other physical and biological dosimetry techniques being evaluated, though not yet practically applicable are: protein biomarkers, hematological changes, chromosomal damages, micronuclei and thermoluminescence [4].

2.3. Indirect dose assessment in non-occupational populations

Personal dosimetry is mainly used for the protection of radiation workers to ensure that the exposure to ionizing radiation is kept within dose equivalent limits. When a larger population is exposed to radionuclides dosimeters are not available in sufficiently large numbers. An exception is the internal dose to the thyroid gland which can be accessed via direct thyroid scans of radio-iodine uptake. The external dose contribution and the contributions from other radionuclides are more difficult to assess, especially multi-organ or whole-body doses.

Instead environmental monitoring from both stationary and mobile dosimeters can map geographical patterns of contamination. From these environmental data indirect dose assessments can be calculated for larger populations. External radiation doses to a population can be estimated via deposition maps, meteorological modeling or distance from the radiation source, including factors such as shielding. Internal doses can be measured for a limited amount of subjects via whole-body counting or thyroid scanners, but for most of the population estimations of doses can be made based on residence, inhalation and ingestion assumptions. An example of a well-developed model for indirect dose assessment is the Radiation Effects Research Foundation (RERF) dose estimation model (DS02R1) from an atomic bomb. The model takes into account distance to the hypocenter, shielding from buildings and terrain [1].

2.4. An example of indirect dose assessment among Swedish hunters

Using transfer factors based on whole-body counting from the Swedish population an example of a model for the assessment of life-time (70 years) extra dose from the Chernobyl fall-out was calculated for 16,000 hunters with families in the three mostly contaminated counties in Sweden. An extra life-time dose up to 9.4 mSv was calculated, depending on the factors age, gender and habitat. About 75% of the life-time dose was from internal contamination from food [5].

If only the external dose contribution is accounted for during the first year the relative dose contribution from so called short-lived fission products was 36%, 37% for cesium-134 and 27% for cesium-137. After 70 years the proportions were 11%, 29% and 60% respectively [6].

2.5. Dose assessment among reindeer herders

The highest radionuclide exposure to a population outside the former Soviet Union after the Chernobyl accident was received among Nordic reindeer herders, receiving about 10–100

times higher doses than urban populations, according to Swedish whole-body counts [7]. The reindeer livelihood was severely affected by the Chernobyl fall-out. Due to radiation protection actions about 80% of the Swedish reindeer meat was destroyed the first years following the accident, and the slaughter had to be moved from winter season to summer, when browse was less contaminated. Middle aged reindeer herdsman also received similar or even higher doses from the global fall-out during the 1950ies and 1960ies making them exposed twice [8]. According to population data from Statistics Sweden there are only about 700 reindeer herders by occupation in Sweden, which gives too low power for epidemiological analyses on cancer incidence, but a combined study from all Nordic countries might be possible.

3. Use of national health data registries

Although the LSS-cohort outcome is the supposedly golden standard for cancer risk there is a fundamental shortcoming due to lack of early data covering the Hiroshima and Nagasaki prefecture populations, since prefecture cancer registries were not in use until 1958. Furthermore the LSS-cohort is mainly based on mortality data although cancer incidence registries usually are based on histological sampling with higher diagnostic accuracy. This gives uncertainties to the LSS-data concerning early health effects for the cancer risk models. In Japan a “National Health Promotion” law put in place in Japan in the early 2000s said that prefectures must track illnesses including cancer. This law led to the introduction of some new cancer registries in Japan. The Fukushima prefecture begun a cancer registry in 2010 using a standardized database system governed by the Japanese National Cancer Center. But the data produced in the first few years the cancer registry was of poor quality and is still being developed by the year 2017. This is a great drawback for the estimation of health outcomes, including cancer, for the population of the Fukushima prefecture following the nuclear accident in 2011.

The lack of official health data or a national health data base were even more striking in the former Soviet union at the time of the Chernobyl accident in 1986. The absence of data for researchers has made follow-up of health outcomes difficult in the former Soviet states, though national cancer registries are now built up in Belarus, Ukraine and the Baltic states.

In the Nordic countries there are national cancer registries at the individual level covering all population. In Sweden a national cancer registry is in use since 1958 [9]. Good quality cancer registries make it possible to register changes in baseline incidences following environmental changes such as radio-nuclide releases to the population, especially as a complement when dosimetry is absent or very inexact.

3.1. The example of detecting increased cancer incidence in South Wales around Windscale

The first population study apart from the LSS-cohort showing a possible increased risk of cancer was in South Wales. From a fuel reprocessing plant at Windscale waste was discharged into

the Irish Sea via a pipeline and deposition occurred in the sea bottom, fish and sea weed. The fission product ruthenium-106 was taken up very efficiently and concentrated in the sea weed *Porphyra umbilicales*. It was harvested and used in laver bread, consumed mainly in South Wales. The use had to be stopped. The activity in fish was mainly from cesium-137. When an ecosystem is contaminated with radionuclides and local food is the main source of internal exposure to radiation the individual doses to the population are very difficult to assess since food habits and lifestyle differ fundamentally between individuals and regions. Whole-body counting can be made to a small sample of the population, mainly concerning gamma-radiation from gamma-emitting nuclides and indirectly from alpha-emitters with gamma-decay, but has lower sensitivity for detecting the beta-radiation, such as from ruthenium-106. Therefore health surveillance via national cancer registries was fundamental to monitor the health effects to the population with an ecosystem is contaminated by radionuclides. Several epidemiological studies have shown increased incidences of cancer of the population around Windscale [10].

3.2. The example of detecting increased cancer incidence for people living at the Techa river

In 1949 the Mayak Production Association, located in the Southern Urals, started production of plutonium for the Soviet Nuclear weapons program. A cohort of 30,000 residents of 40 rural villages along the Techa river or the Chelyabinsk City with low-dose and low-dose-rate exposures have been followed for more than 50 years for incident cases of cancer. Individual radiation doses were based on geographic information of residence and food habits. Calculated external exposures were due to gamma rays from contamination of the soil and the internal exposures were assessed from expected consumption of water, milk and food containing uranium fission products. All solid cancers as a group were related to stomach doses ranging from 0 to 960 mGy with a mean of 60 mGy. Dose-response between estimated radiation dose and solid cancers and leukemia were shown with an excess relative risk (ERR) after exposure to 100 mGy of 0.08 [11].

3.3. The example of detecting increased incidence of thyroid cancer in Ukraine after the Chernobyl accident

Chemical composition, deposition, uptake and metabolism of iodine make thyroid dosimetry complicated, but direct measurement using a gamma-meter of the thyroid gland can be made. To estimate individual thyroid absorbed doses from radioiodine in the Ukrainian population from May-June 1986, more than 150,000 individual examinations were carried out by special dosimetric teams. The collective thyroid dose was 64,000 person-Gy, which theoretically could give about 300 extra cases of thyroid cancer [12].

Another study was performed on behalf of the International Agency for Research on Cancer (IARC). A population-based case-control study was designed of thyroid cancer among young people who lived in the areas that were heavily contaminated by the Chernobyl accident. Indirect dosimetry was performed based on data of the habitat and dietary habits of 1615 cases and controls aged 0-18 y at the time of the accident. A strong dose-response relationship was observed between estimated radiation dose to the thyroid received in childhood and thyroid cancer risk [13].

3.4. The example of detecting increased cancer incidence in Sweden after the Chernobyl accident

Sweden received the largest deposition of radionuclides outside the former USSR, where about 4.4% of the total Chernobyl fall-out was deposited [14]. Deposition was strongly dependent on local weathering giving highest deposition in coastal areas around the Bothnian sea. A food regulation program was introduced to assure that the annual extra dose did not exceed 1 mSv in the population. In a study indirect individual doses were assessed for 734,537 persons living in the three most contaminated counties in Sweden. Personal dosimetry could not be performed 30 years after the accident, so a cumulative exposure based on measured ground activity of cesium-137 of the residence of the subjects. A cumulative exposure estimate during 5 years following the accident was used as proxy for received dose. 82,495 cases of cancer were diagnosed from 1991 to 2010 and retrieved from the Swedish national cancer registry. A non-parametric dose-response could be shown between the deposition of cesium-137 and cancer incidence [15].

4. Conclusion

A paradigm shift is needed from the dominance of radiation protection to a more biologically based health risk assessment from ionizing radiation. Models for radiation protection are made for regulatory purposes and do not directly reflect the risk of disease. Also dose estimates are poorly applicable for risk assessment for populations exposed in the low dose region. Only to rely on technical surveillance could be insufficient. Instead other approaches using national health databases in combination with environmental monitoring could be more efficient for the detection of health risks. Medical surveillance and health registries are good complements, especially in the absence of dosimeter data, complex environmental exposures and when large populations are exposed. When nuclear facilities are in use national health registries could be the most sensitive source for the detection of increased cancer incidence and other disease from nuclear accidents or other emission of radionuclides to the environment. Apart from nuclear power plants possible exposure could emanate from uranium mining, fuel processing, nuclear waste processing and nuclear waste repositories.

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