

in the incidence of thyroid diseases due to earlier detection of non-symptomatic cases (screening effect).

Information on possible effects of screening programmes on the reported thyroid cancer incidence can be obtained from the Adult Health Study (AHS) of the Japanese survivors of the atomic bombings of Hiroshima and Nagasaki, and from post-Chernobyl studies. The AHS sample is a subset of the full cohort of the atomic bomb survivors Life Span Study (LSS) who volunteered to undergo medical examinations every second year. The reported thyroid cancer incidence in the AHS was higher than in the full LSS cohort due to a screening effect (70). A screening effect was also observed among populations who had high thyroid exposures due to the Chernobyl accident and who were subjected to intensified surveillance of thyroid diseases (142,143).

The epidemiological follow-up of persons involved in a radiation emergency has the general goal of detecting radiation effects or diseases that are potentially related to radiation exposure. The specific purposes of the follow-up are:

- to identify radiation effects in a group of people known (or presumed) to have been exposed to ionizing radiation;

Box 9. The Fukushima Health Management Survey

The Fukushima prefectural government launched the Fukushima Health Management Survey at the end of June 2011 to assist in the long-term health management of Fukushima residents (147). The study, conducted by Fukushima Medical University, has the primary purpose of monitoring the long-term health of residents, promoting their future well-being and determining whether long-term low-dose radiation exposure has health effects. The Fukushima Health Management Survey consists of a basic survey covering the population of Fukushima (2 million people) and four detailed surveys: a thyroid ultrasound examination (residents between 0 and 18 years), a comprehensive health check (residents of all ages living in the evacuation zones), a mental health and lifestyle survey (residents of all ages living in the evacuation zones) and a pregnancy and birth survey (of around 16 000 women who received maternal and child health care in Fukushima prefecture).

The aim of the basic survey is to determine the whereabouts of every prefectural resident from the time of the 11 March nuclear accident onwards (a “record of movement”) and will provide a basis for the estimation of individual radiation doses (external exposure) that will then be linked to data on internal exposure as measured by whole-body counters, with

detailed data from the other four detailed surveys, cancer registries and vital statistics.

By the end of August 2012 responses from more than 470 000 questionnaires had been collected. The thyroid ultrasound examination collected data from more than 80 000 children and adolescents. Thus far, about 74 000 (April 2011 to March 2012) and 16 000 (March 2012 to April 2012) of 210 000 people have been included in the comprehensive health check, and around 92 000 of 200 000 people have answered the mental health survey. About 9 000 women replied to the questionnaires on pregnancy and birth. This large-scale long-term cohort study is expected to provide data on radiation health effects and disaster-related stress.

At the time of this publication, interim data from the Fukushima Health Management Survey indicate that external exposure for 93.8% of the respondents was less than 5 mSv and that for 99.2% of residents’ external exposure was less than 10 mSv, with a highest estimate of 25.1 mSv (118,148). Internal exposure was estimated in 81 000 residents by WBC between June 2011 and September 2012; the reported committed effective doses were below 1 mSv in 99.9% of the persons surveyed, and the maximum dose was 3 mSv (117,118).

- to determine whether the risk of such effects is statistically significantly greater in this group than in a comparable (e.g. by age and sex) unexposed group of individuals;
- to determine whether any identified increased risk is statistically associated with the exposure;
- to determine whether there is a relationship between the increased risk and other factors (e.g. tobacco smoking, exposure to chemicals);
- to derive and refine risk estimates;
- to plan health interventions as necessary.

In addition to the doses, health monitoring and surveillance of people exposed to low radiation doses necessitates consideration of legal, social, economic and psychological factors, which go beyond the scope of the present report. In some cases, even if there is insufficient evidence to recommend long-term follow-up for stochastic effects (i.e. cancer) from a medical management perspective, it is prudent to develop a registry and conduct epidemiological research.

Several factors influence the possibility of detecting a statistically significant increase in cancer morbidity or mortality through a radiation epidemiology study. The level of radiation dose is a major factor in determining the size of the population to be studied in order to give a sufficient statistical power to the study. Hundreds of thousands or even millions of individuals may be needed to detect an increase after a low-dose radiation exposure, because the differences compared with background incidence or mortality (i.e. baseline rates) are small (141,144). Epidemiological detectability in terms of excess absolute risk increases in population subgroups for which baseline rates are lower than those of the general population (e.g. thyroid cancer incidence in children). All these factors must be taken into account when planning and implementing long-term follow-up programmes for the Fukushima Daiichi NPP accident. This topic has been discussed in previous WHO publications (22,141).

Population screening and health surveillance programmes often include medical imaging that can help identify an increase in cancers and other conditions. However, medical imaging procedures can result in effective doses that exceed the exposure levels estimated to have occurred in residents of Fukushima prefecture as a result of this accident. The radiation risks of medical imaging, particularly in children, have been extensively addressed and evidence from epidemiological studies is available (145,146). The benefits of the medical applications of radiation outweigh the risks when radiation is used but the opposite may be true if procedures are performed without a clear clinical indication. The need for justification of medical exposures is particularly relevant in long-term follow-up of large populations. Mass screening using radiological imaging procedures may result in substantially more radiation exposure and risks than those assessed in the present report (in the general population and in the workers).

In addition to the Fukushima Health Management Survey, as part of occupational health programmes, a special medical follow-up protocol for emergency workers is being followed (see Box 10).

Besides medical follow-up of the most affected parts of the population, continued environmental monitoring and monitoring of the food and water supply, with strict enforce-

ment of existing regulation, is a further important component of the long-term goal of decreasing radiation exposure to be as low as possible.

7.4 Psychological consequences of the accident

Although the assessment of mental health risk is beyond the scope of this HRA, this topic is highlighted as a challenge to the medical community and health authorities that may have an impact at all levels of society. The psychosocial impact is one of the major consequences of nuclear emergencies; this was one of the lessons learned from the Chernobyl accident (141,149). As with the Chernobyl accident, the psychological impact of the Fukushima accident may outweigh other health consequences (150).

Psychological reactions following disasters may include multiple symptoms such as fear, grief, anxiety, anger, depression and distrust (151). These reactions may be exacerbated in radiation emergencies because radiation cannot be perceived by the senses and most people either do not know or do not fully understand the terminology used to express the size of exposures and their potential effects. As a result, community-wide feelings of helplessness and vulnerability may arise. Those disasters with a high degree of uncertainty about potential future health effects are more psychologically traumatic than situations with more visible, immediate and predictable outcomes.

A high incidence of psychosomatic symptoms, psychological distress and psychiatric disorders has been observed among victims of radiation accidents. Parents with young children (152), pregnant women, children, elderly persons, emergency workers, people with pre-existing mental disorders, clean-up workers (153), evacuees (154) and the population as a whole in some instances (155) may all be at increased risk. Acute stress reactions typically include physical, emotional, cognitive and interpersonal effects. A persistent state of anxiety may result in chronic stress reactions that have behavioural, emotional and physiological consequences. Some people may develop mental disorders such as post-traumatic stress disorder (PTSD), anxiety disorders, depression and alcohol use disorder.

Box 10. Medical follow-up of emergency workers at TEPCO

All emergency workers responding to the accident at the NPP were enrolled in a medical follow-up programme. Workers who have since left their jobs have an opportunity to continue enrolment. The items included in the medical examination for the follow-up vary according to the doses:

- all workers: general medical examination required by law and psychological evaluation;
- workers > 50 mSv: general medical examination required by law; psychological evaluation; and examination of lens of the eyes (cataract);
- workers > 100 mSv: general medical examination required by law; psychological evaluation, examina-

tion of the lens of the eyes (cataract); thyroid test, cancer screening (lung, stomach, and colon).

The medical examination includes clinical evaluation, blood and urine tests, visual and auditory acuity, electrocardiogram, thyroid hormones, thyroid ultrasound, and imaging procedures.

More information is available at:

<http://www.mhlw.go.jp/stf/houdou/2r9852000001plbx-att/2r9852000001plen.pdf>

The psychological impact of the 2011 Great East Japan Earthquake and Tsunami was compounded by the subsequent nuclear accident at the Fukushima Daiichi NPP. For many people, the Fukushima Daiichi NPP accident resulted in many stressors that constitute a potentially traumatic situation. In addition to the significant impact of the loss of lives and missing loved ones because of the earthquake and tsunami (134), other conditions such as evacuation, relocation, material and financial loss – as well as fear and uncertainty related to radiation exposure and its potential consequences – increased the mental health impact of the combined disaster. As of September 2012, 329 777 people remain relocated or evacuated (156).

Early management of mental health issues is important (141,157,158). Most people with common psychiatric symptoms such as anxiety and depression do not seek professional care, and those who do seek care often present to general practitioners or paediatricians with physical symptoms. Consequently, medical practitioners need to understand the full scope of health effects of radiation exposure, to recognize and manage psychosomatic, anxiety or depression symptoms and to treat mental and physical health with equal respect (159).

The psychosocial effects of radiation accidents may extend far beyond the geographical area of impact because of people's worries about future risks. The size of the population exhibiting chronic stress may be quite large and social stigma attached to residents of affected areas may exacerbate the problems.



8. Summary and conclusions

This report presents the results of a HRA of the Fukushima Daiichi NPP accident for the general population and for workers dealing with the emergency. The assessed health risks include cancer and non-cancer effects of exposure to radiation, encompassing both stochastic and deterministic health effects.

8.1 Health risk assessment in the general population

Health risks in the general population were assessed in different geographical locations inside and outside Japan, for both sexes and three age-at-exposure groups: 1-year-olds (infants), 10-year-olds (children) and 20-year-olds (young adults). These age groups were considered suitable to permit the characterization of risks for younger and more sensitive populations.

Based on the doses estimated to be substantially below threshold levels, deterministic effects (i.e. tissue reactions) are not expected. For this reason, no increase in the incidence of spontaneous abortions, miscarriages, perinatal mortality, congenital malformations, developmental abnormalities or cognitive impairment is expected as a result of *in utero* radiation exposure.

A risk of radiation-induced hereditary effects has not been definitively demonstrated in human populations. Based on animal data, international scientific bodies consider that any risk of hereditary effects for the offspring of those who were exposed before they have conceived children would be much lower than the additional lifetime risk of cancer for the exposed individual him- or herself (about one order of magnitude lower).

The present results suggest that the increases in the incidence of human disease attributable to the additional radiation exposure from the Fukushima Daiichi NPP accident are likely to remain below detectable levels.

The predicted magnitude of cancer risks was assessed for leukaemia, thyroid cancer, female breast cancer and all solid cancers combined. The risks were calculated over a lifetime and over the 15 years following the accident. The lifetime attributable risks (LAR) were quantitatively estimated only in the most affected parts of Fukushima prefecture. For all other locations in Japan and around the world, the radiation-related cancer risks were estimated to be much lower than the usual fluctuation in the baseline cancer risks.

The results show the largest additional cancer risks among those exposed in infancy (leukaemia in males and solid cancers in females). Given the exposure to radioactive iodine, during the early phase of the emergency, the lifetime attributable risk of thyroid cancer was specifically assessed. The results show the greatest risk among girls exposed as infants in the most affected area in Fukushima prefecture, although the excess absolute risk is small, because of the low baseline risk of thyroid cancer, it represents a comparatively high relative increase in the lifetime risk of up to around 70% (as an upper

bound). The high relative risk of childhood thyroid cancer becomes more evident when risks are calculated over the first 15 years after the accident for those exposed as infants, because the baseline thyroid cancer risk in early life is very low. Monitoring children's health is therefore warranted.

The risk of leukaemia as a result of radiation exposure from the accident was assessed to be greatest in males exposed as infants in geographical locations with the highest exposure, slightly above 5% over baseline risk as an upper bound. A similar result is found for breast cancer in girls exposed as infants. For all solid cancers, a maximum relative increase of about 4% was estimated.

8.2 Health risk assessment in emergency workers

To date, the Fukushima Daiichi NPP accident has not resulted in acute radiation effects among workers. None of the seven reported deaths among workers is attributable to radiation exposure¹. Thyroid dysfunction was reported in three workers as a result of repeated self-administration of stable potassium iodide for thyroid blocking against radioactive iodine. This effect was transient and thyroid function returned to normal once the administrations were stopped.

The potential health consequences of exposure to radiation of the emergency workers have been assessed assuming four scenarios that describe different exposure patterns. Scenario 1 represents around two thirds of the emergency workers with quite low doses to all tissues. Scenario 2 contains about one third of the emergency workforce who received moderate thyroid doses and lower doses to other tissues. Scenarios 3 and 4 represent upper bounds for external and internal exposure respectively. Scenario 3 concerns less than 1% of workers who received higher, more homogeneous tissue doses (including thyroid doses). Scenario 4 relates to those few workers who received high thyroid doses as a result of inhalation of radioactive iodine and lower doses to other tissues.

Because tissue doses received were below threshold doses, no deterministic effects of radiation are expected in the workers, apart from possible thyroid disorders in those few workers who inhaled significant quantities of radioactive iodine.

Cancer risks were calculated for workers aged 20 years, 40 years and 60 years. The estimated risks were consistently lower for workers exposed at an older age. Relevant findings are summarized below. For around two thirds of the emergency workers (Scenario 1), all calculated risks are of similar magnitude as the normal fluctuations in the baseline cancer risks. For about one third of the workers (Scenario 2), the relative increase over background for thyroid cancer is estimated to be up to 20% for the youngest workers. For less than 1% of workers (Scenario 3), the relative increase over background for leukaemia and thyroid cancer is as high as 28% in the youngest workers. For those few emergency workers who received very high doses to the thyroid (Scenario 4), a notable risk of thyroid cancer is estimated, especially for young workers.

1. The causes of these deaths have been reported as disaster-related (two cases), heart attack (three cases), sepsis (one case) and leukaemia (one case for which the time of the onset was shorter than the minimum latency period for radiation-induced leukaemia).

There may be an increased risk of long-term circulatory disease among workers with the highest doses (Scenarios 3 and 4), which is likely to be substantially smaller than any additional cancer risk.

The considerations made above for heritable risks in the general population (section 8.1) are also applicable to workers.

8.3 Final considerations

This HRA was drawn up to give an indication of the health implications of the Fukushima NPP accident for the identification of needs and priorities for public health actions. The estimates presented in the report must be regarded as indicative of the magnitude of the health risks based on best judgment rather than as precise predictions.

The estimation of radiation risks, at doses below which increases in cancer incidence have been readily observed in epidemiological studies, involves a number of uncertainties. The main sources of uncertainty in this HRA were discussed in chapter 6. Owing to the preliminary nature of the dose estimation and the time frame for the HRA Expert Group to complete its work, a fully quantitative assessment of the uncertainties associated with the LAR central estimates was not performed.

Although substantial information on radiation risks is available, further evidence would be highly desirable. This accident highlights the need for continuing and improving low-dose and low-dose-rate radiation research.

To avoid any underestimation of risks, the HRA Expert Group adopted the LNT model as the most reasonable approximation of the relation between low-dose radiation exposure and cancer risks and made the prudent choice of not applying a dose and dose rate effectiveness factor (DDREF). Because this HRA is based on a LNT model and the risk quantity adopted (LAR) is proportional to the dose, more refined risk estimations can be provided in the future if a more detailed dose assessment becomes available.

The HRA Expert Group considers the risk estimates robust on the basis of existing knowledge and information at the time of this assessment. The input data and risk models used are considered to be the most appropriate at present. An effort was made to avoid any underestimation of risks when adopting assumptions; hence, any possible bias is likely directed toward overestimation of health risks.

This HRA is not intended to provide estimates of disease burden in the population or cases of excess disease resulting from radiation exposure. This report uses preliminary dose estimates based on environmental and food monitoring data for the calculation of lifetime attributable risks. This makes no assumption of how many persons were exposed according to the different exposure scenarios, for which distributions of individual dose estimates are needed. In addition to the environmental and food monitoring data, an evaluation of the population dose distribution requires the knowledge of the behaviour of persons, e.g. how much time they spent in the differently exposed areas. Moreover, population figures by sex, age and area were not considered for this report, especially in light of the expected substantial migration and movement in the months following the accident. Reliable numbers would be needed for the estimation of population doses and associated risks. Provided these become available, such assessment could be performed

in future studies, such as the upcoming 2-year UNSCEAR study and the on-going survey conducted in Fukushima prefecture to determine the whereabouts of the residents.

It is important to note that this is a report on radiation health risks and that it does not refer to radiation-induced health effects. While radiation risks can be estimated prospectively, radiation-induced health effects are assessed retrospectively and this requires a long-term follow-up of the exposed population. Surveillance of health and monitoring of disease occurrence is required for empirical assessment of the health consequences of the accident and quantification of health outcomes resulting from it.

The Fukushima Health Management Survey is expected to contribute to future health effect assessments. Population health surveillance will permit the identification of additional needs for the delivery of health care. In addition, as part of the occupational health programmes, a special protocol for medical follow-up of emergency workers is being adopted. These initiatives are also relevant for the mitigation of the psychosocial impact of this accident and the prevention of adverse mental health consequences, which are considered to be of major significance.



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