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Estimated Long Term Health Effects of the Chernobyl Accident

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ABSTRACT

Apart from the dramatic increase in thyroid cancer in those exposed as children (see Background Paper 2), there is no evidence to date of a major public health impact as a result of radiation exposure due to the Chernobyl accident in the three most affected countries (Belarus, Russia and Ukraine). Although some increases in the frequency of cancer in exposed populations have been reported, these results are difficult to interpret, mainly because of differences in the intensity and method of follow-up between exposed populations and the general population with which they are compared.

If the experience of the survivors of the atomic bombing of Japan and of other exposed populations is applicable, the major radiological impact of the accident will be cases of cancer. The total lifetime numbers of excess cancers will be greatest among the 'liquidators' (emergency and recovery workers) and among the residents of 'contaminated' territories, of the order of 2000 to 2500 among each group (the size of the exposed populations is 200000 liquidators and 3700000 residents of 'contaminated' areas). These increases would be difficult to detect epidemiologically against an expected background number of 41500 and 433000 cases of cancer respectively among the two groups.

However, the exposures for populations due to the Chernobyl accident are different (in type and pattern) from those of the survivors of the atomic bombing of Japan (and doses received early after the accident are not well known). Predictions derived from studies of these populations are therefore uncertain. Indeed, although an increase in the incidence of thyroid cancer in persons exposed as children as a result of the Chernobyl accident was envisaged, the extent of the increase was not foreseeable. In addition, only ten years have passed since the accident. It is essential, therefore, that monitoring of the health of the population be continued in order to assess the public health impact of the accident, even if any increase in the incidence of cancers as a result of radiation exposure due to the Chernobyl accident, except for leukemia among liquidators and thyroid cancer, is expected to be difficult to detect.

Studies of selected populations and diseases are also needed in order to study observed or predicted effects; careful studies may in particular provide important information on the effect of exposure rate and exposure type in the low to medium dose range and on factors which may modify radiation effects. As such, they may have important consequences for the radiation protection of patients and the general population in the event of any future accidental exposure.

1. THE ISSUES

Ionizing radiation is one of the best studied carcinogens in the human environment. Hundreds of thousands of persons exposed to radiation around the world (survivors of the atomic bombing in Japan, patients irradiated for therapeutic purposes, workers exposed occupationally) have been followed up for decades. Many large scale animal experiments have been carried out and much experimental work has been performed to understand the mechanisms of radiation damage at the cellular and molecular level and quantify its effects. The major long term effects identified [1–5] are an increase in the frequency of cancers and cataracts and, among those exposed in utero, a higher frequency of congenital anomalies. A small increase in hereditary effects has also been observed in animal experiments.

Predictions concerning the likely radiological consequences of the Chernobyl accident have been made on the basis of these data. Much of the data accumulated to date, however, are from studies of populations that have received relatively high doses in an acute or fractionated fashion, often from external radiation. Uncertainties remain concerning the exact magnitude of the health effects of the exposures received by populations as a result of the Chernobyl accident, in particular:

(a) the assumptions necesssary to estimate the effects of relatively low doses[1], such as those resulting over large areas following the Chernobyl accident;
(b) the effects of protracted (chronic as opposed to acute) exposures, such as were received by populations exposed environmentally and some of the liquidators[2];
(c) the effects of different radionuclides and different radiation types;
(d) the effects of factors which may modify radiation induced risks (including age at exposure, sex, possible genetic predispositions and other host and environmental factors).

Ten years have now passed since the Chernobyl accident and it is timely to summarize what long term health effects have been observed up to now, whether they agree with predicted effects and what might be expected to be seen in coming years and decades. In this Background Paper the organization of the epidemiological follow-up of exposed populations in the three most affected countries (Belarus, the Russian Federation and Ukraine), the levels of radiation doses they received, the health consequences expected on the basis of previous epidemiological studies of populations exposed to radiation, and the main results to date are reviewed. Four groups of exposed populations (see Table I) are considered separately, where possible:

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[1] In the range 0–300 mSv over a lifetime.

[2] Results from experiments with animals suggest that the risk per unit dose is lower for protracted (chronic) exposures than for acute exposures.

1. The 'liquidators' (also referred to as cleanup or recovery workers): they include persons who participated in the cleanup after the accident (cleaning up the plant and its surroundings, construction of the sarcophagus, decontamination, building of roads, destruction and burial of contaminated buildings, forests and equipment), as well as many others, including physicians, teachers, cooks and interpreters who worked in the 'contaminated' territories.
2. The 'evacuees': those who were evacuated from the town of Pripyat and the 30 km zone around the Chernobyl plant in April–May 1986;
3. The residents of the 'strict control zones' (SCZs): those members of the general population who have continued to live in the more heavily contaminated areas (with level of ^{137}Cs deposition greater than 555 kBq/m^2), typically within a few hundred kilometres of the Chernobyl plant. Within these areas, radiation monitoring and preventive measures have been taken to maintain doses within permissible levels.
4. The general population of the 'contaminated' territories in the three countries.

The primary focus of this Background Paper is the estimation of the burden of cancer resulting from the accident: the major long term effect expected on the basis of studies for high doses. Thyroid cancer, which has been observed to increase dramatically in children exposed at the time of the accident, is discussed in more detail in Background Paper 2. It is too early to assess genetic effects, and the absence of systematically collected data on genetic and other effects (cataracts, congenital anomalies) in most of the affected countries make it difficult to draw any conclusions about these. In comparison with other European countries, relatively high levels of contamination were recorded in Bulgaria, Austria, Greece and Romania, followed by other countries of central, southeast and northern Europe. However, effects of radiation exposure due to the Chernobyl accident outside the three countries most affected are not discussed, since the levels of exposure were very low and any effects of the exposure to be expected to date would be undetectable [6–8]. Clinically attributable effects of acute exposure are discussed in Background Paper 1.

2. BACKGROUND

2.1. Background scientific knowledge about radiation risks

Ionizing radiation is one of the agents in the environment for which genetic and cancer risks have been best studied and characterized. This is mainly due to two facts: (1) very large numbers of exposed persons have been followed up for decades; and (2) exposures to radiation, unlike for many other environmental agents, are relatively easy to reconstruct, on an individual level, at least for radiation exposures at high dose rates and high doses. The information available to date on radiation risks comes from several sources:

- epidemiological studies of large populations that have received relatively high doses of gamma or X radiation at a high dose rate (survivors of atomic the bombing, patients treated by radiotherapy for malignant or benign diseases) or doses due to radon protracted over many years (hard rock miners, particularly uranium miners) [1, 9, 10];
- more recently, large scale epidemiological studies of populations having received low doses in a protracted fashion as a result of their occupation, mainly in the nuclear industry [1, 11, 12];
- large scale animal experiments carried out in order to understand the effects of different radiation types, exposure levels, patterns of exposure and modifying factors [1, 9, 10];

- cytogenetic, molecular and genetic studies aimed at understanding the mechanisms of radiation induced carcinogenesis [2, 9].

The major long term effects identified [1–5] are an increase in the frequency of cancers, particularly leukaemia, and of cataracts and, among those exposed in utero, a higher frequency of congenital anomalies. A small increase in genetic effects has also been observed in animal experiments.

The temporal patterns of radiation risks have been observed to differ markedly for leukaemia and solid cancers. In the follow-up of the survivors of the atomic bombing, excess risk for leukaemia increased sharply after the bombing, reaching a peak 3–10 years after exposure, followed by a gradual decline [13]. The temporal pattern of leukaemia risk was markedly modified by age: in general, the younger the age at exposure, the higher the initial excess risk and the steeper the subsequent decline. Among those exposed as adults, the decline was less pronounced for women than men.

The excess solid cancer risk, however, appeared gradually, starting 5–10 years after exposure, and increased roughly in proportion to the background cancer rates (these typically increase with advancing age). The excess relative risk (i.e. the proportional increase in risk relative to background risk) for solid cancers depended on age at exposure and sex. It was generally higher for those exposed at younger ages and for women. The temporal pattern of the relative risk has been remarkably constant during the follow-up [14], except for those exposed early in life, for whom the relative risk has been decreasing with the passage of time. Thyroid cancer risk has followed a similar temporal pattern [15]. A recent pooled analysis of seven studies suggests that the excess relative risk of thyroid cancer among those exposed as children (below the age of 15 years) remains elevated for many years, declining only 30 years after exposure [16].

2.2. The follow-up of populations exposed to radiation as a result of the Chernobyl accident: organization and problems

2.2.1. Chernobyl Registry follow-up

The Chernobyl Registries were established initially as a single 'All-Union Distributed Registry' located in Obninsk, Russia, by a 1987 directive of the Ministry of Public Health of the USSR [17]. The aim was to set up a comprehensive registration and follow-up system for the persons most affected by the Chernobyl accident. The directive identified four groups of subjects – the groups of 'primary registration' – for whom registration and 'active' follow-up was mandatory: participants in the 'liquidation' of the consequences of the Chernobyl accident, the so-called 'liquidators'; subjects evacuated from the most contaminated territories (>1480 kBq/m^2); persons living in 'contaminated' areas (> 555 kBq/m^2); and children of the above groups. Since the dissolution of the USSR, the responsibility for the State Chernobyl Registries has been passed to the individual countries.

As a consequence of this directive, all persons included in the State Chernobyl Registries are 'actively' followed up: they must undergo an annual medical examination in which they are systematically examined by a general practitioner and a number of different specialists. The subject is also directed, as appropriate, for additional examinations to oncologists and other specialists.

All data on diseases diagnosed during the annual medical examination, as well as at any other time during the year, is sent to the Chernobyl Registry for inclusion in the registry database. In addition to medical data, the State Chernobyl Registries includes demographic variables, information on location and behaviour (food and milk consumption, time spent in 'contaminated zones') at the time of the accident and on work in the Chernobyl area, and, when available, dosimetric information.

2.2.2. Monitoring of the health of the general population

Means are also available in the affected countries to carry out 'passive' follow-up of exposed persons and of the general population with the use of population registries – of mortality, cancer and other diseases.

Mortality

In each country of the former USSR, population registration is carried out at the local level in the address bureaux (where the addresses of present residents are kept) and the ZAGs (buro zapicii akta grazhdanskovo sostoyania), which compile all information about birth, marriage, divorce and death of persons living in the administrative area. There is no centralized registry, however, and results of a recent pilot study [18] indicate that considerable time and effort may be needed for tracing subjects who have moved from one area to another. In Belarus, centralization of population registry data is under way; this will increase the feasibility of mortality follow-up of populations. Little information is available currently, however, on the adequacy of mortality data in the affected states.

Cancer incidence

A computerized national Cancer Registry that has been functioning in Belarus since the 1970s registers all cases of malignant neoplasms. A comprehensive registry of Haematological Diseases also exists in Belarus, in the Institute of Haematology and Blood Transfusology, and a registry of childhood thyroid cancer cases in the Institute for Thyroid Pathology in Minsk, where most of these tumours are operated. These registries have proved to be valuable tools for epidemiological follow-up in Belarus [19–23]. They may, however, all be improved with the adoption of international standards for coding, classification and quality control.

In Russia and the Ukraine, no centralized cancer registration system was in place at the time of the accident. Work is under way in both countries to set one up – at least in 'contaminated' areas in Russia [20]. At present, however, routine data on cancer morbidity in these countries is obtained from local oncological dispensaries and verification of the completeness and accuracy of the diagnosis information and checks for duplication are not systematically performed. For persons included in the Chernobyl Registry, moreover, information on cancer diagnosis is often obtained from the records of medical visits in local medical centres; if a patient is referred to the regional or national level for confirmation and treatment and the diagnosis is changed, the information is not necessarily sent to the Chernobyl Registry. A recent study in Russia [18] confirms that the diagnostic information in the Chernobyl Registry is not always accurate. The lack of verification and quality control is actively being remedied. However, this lack must be kept in mind when interpreting results of studies of cancer incidence among exposed populations in those countries.

General morbidity

Information is also available systematically on the general (i.e. not only cancer) morbidity of the population of the three countries. In the countries of the former USSR, regional out-patient clinics systematically collect information on disease diagnoses for all the residents of the region that they cover (not only on those included in the Chernobyl Registry). This information is summarized locally and is sent, on special statistical reporting forms, at yearly intervals to the Ministry of Health. These forms contain information about the number of cases of acute and chronic diseases diagnosed in a given year in the population in all areas of the country. This information is not broken down by age or sex. No verification of completeness or checking for duplication is possible. This passive system of collection of morbidity data on the population contrasts with the active follow-up carried out, as described earlier, for persons included in the Chernobyl Registry. Comparisons of morbidity based on these sources must therefore be interpreted with caution.

2.2.2. *Ad hoc studies*

A number of factors limit the power of the routine follow-up activities listed above to detect the expected effects of exposure due to the Chernobyl accident, even in the three most affected countries. They include, in particular: the generally low radiation doses received by the majority of exposed populations – and hence, presumably, the low level of risk expected; the difficulties of systematic and complete follow-up; the lack of precise dosimetry (as described in the following); and the movements of populations which have taken place since the accident.

Ad hoc analytical epidemiological studies, focusing on specific diseases and populations, may be a more useful approach for investigating the effects of radiation among the exposed populations [24, 25]. Cohort studies of well defined populations – i.e. studies of groups of individuals who are followed over time, for example the cohort of all children whose thyroid dose was reconstructed from direct measurements made in the days following the accident – are important tools for studying radiation effects if precise individual dose estimates can be obtained and if a systematic and complete follow-up can be achieved. When this is not feasible for logistical and/or financial or other reasons, case control studies, i.e. studies of cases of a disease of interest occurring in a given population (such as cases of leukaemia occurring among liquidators) together with studies of appropriate controls, are a cost efficient and powerful alternative. This type of study allows the collection of relatively detailed individual information on the exposure of interest and on other risk factors (from questionnaires as well as from searches of existing records) at much lower cost since the number of study subjects is much reduced.

Both cohort and case control studies are generally much more powerful than descriptive studies for investigating dose relationships. Indeed, the single most informative study on radiation risks today, that of the survivors of the atomic bombing of Hiroshima and Nagasaki [14], would have provided much less information concerning the relation between radiation exposure and cancer risk if the follow-up had been restricted to an examination of trends of diseases over time and comparisons with non-exposed or the general population.

2.3. Radiation doses to different groups: dose levels and available estimates

Table I presents a summary of the number of persons exposed and the levels of doses received in the four groups described earlier. Much effort has been directed to reconstructing doses on an individual or group level for populations exposed environmentally, mainly for those who were at the time of the accident living in the areas that became most 'contaminated' [26–33]. Less attention has been focused on reconstructing dose levels for the general population living in 'contaminated' territories outside the 'strict control zones' and 'evacuation zones' since, given the level of dose they received, it is unlikely (if our current estimates of risk are correct) that any radiological effect on health could be detected in this population, even though it may well have the largest total collective dose.

Radiation doses for these populations have been estimated in a variety of ways: from direct whole body or thyroid counting (to determine, respectively, the individual body burden and thyroid burden from various radionuclides) and physical measurements of doses due to external irradiation with individual dosimeters, to dose reconstruction using environmental models and questionnaires, and to estimation of dose using biological or biophysical markers of exposure. The accuracy of the dose estimates varies according to the estimation method and the level of dose (for example, more precise and numerous measurements were made in the most contaminated regions).

2.3.1. Liquidators

Approximately 600000 to 800000 persons took part in the cleanup activities to 'liquidate' the consequences of the Chernobyl accident. This includes persons who participated in the cleanup after the accident (cleaning up around the reactor, construction of the sarcophagus, decontamination, building of roads, destruction and burial of contaminated buildings, forests and equipment), as well as many others, including physicians, teachers, cooks and interpreters who worked in the 'contaminated' territories and received on average much lower doses. Approximately 200000 liquidators (see Table I) worked in the region of Chernobyl during the period 1986–1987, when the exposures were more significant.

The dosimetric information available on liquidators is subject to controversy since the personal dosimeters in use in the early days after the accident were too few and generally too limited in range. A reasonable estimate of the average dose received by this group of 200000 people is 100 mSv [28]. Thus the collective effective dose would be approximately 20000 man.Sv. It is noted that some workers received their dose in a matter of minutes – for example working on the roof of the reactor – while others received it over months or even years, and the predominant radiation type and route of exposure varied according to time and to the activities of the liquidators.

Dose estimates have generally been derived in one of three ways:

- individual dosimetry: the liquidator was given a personal dosimeter;
- group dosimetry: an individual dosimeter was assigned to one member of a group of liquidators;
- from itineraries: measurements of gamma radiation levels were made at various points where liquidators worked, and an individual's dose was estimated as a function of the points where he or she worked and the time spent in these places.

It is thought that the level of dosimetric control and the adequacy of dose estimates may vary between civilian liquidators (construction workers, logistic support), military liquidators (soldiers and officers who worked in decontamination, dosimetric control, evacuation) and radiation specialists.

The distribution by dose of liquidators included in the State Chernobyl Registries of Belarus, Russia and Ukraine is shown in Table II. It is noted that doses are missing in these registries for a substantial proportion of the liquidators. Liquidators who worked in the first year generally had higher recorded doses than those who worked in subsequent years. Throughout this paper, efforts are made, where possible, to restrict the presentation to those liquidators who worked in the 30 km zone in 1986–1987, since they are most likely to have actually participated in the cleanup activities.

2.3.2. Evacuees

The evacuees are the former residents of the 30 km zone. There were approximately 135000 persons evacuated, including the 49000 residents of the town of Pripyat. The evacuation of Pripyat and other locations close to the plant was completed within approximately 40 hours of the accident. Approximately 40000 additional residents of the 30 km zone were evacuated on 3–5 May 1986 and the evacuation of the 30 km zone was completed during the period 5–14 May [32].

Most of the dose was received in a short time period and resulted from external exposure from the passing cloud and from radionuclides deposited on the ground or other surfaces. Initial reports by Soviet scientists [30] were that this population had received a collective effective dose from external exposure of 16000 man.Sv. More recently the doses from external exposures have been re-evaluated by Likhtarev et al. [32]. This re-evaluation was based upon dose rate data from many locations within the 30 km zone, and the results of a survey of 42416 evacuated residents. Individual doses were reconstructed for 13383 inhabitants of Pripyat and 17203 residents of other settlements. The average dose to the residents of Pripyat was 11.5 mSv and that of residents of the other evacuated locations was 18.2 mSv. The calculated individual doses vary widely; the maximum value was stated to be 383 mSv. The collective effective dose from external exposure for the entire evacuated population is estimated to be 1300 man.Sv. The collective effective dose from other exposure pathways is not believed to add substantially to the indicated total.

2.3.3. Human exposure in 'contaminated' areas

Currently, there are approximately 4 million people who reside permanently in areas with an activity density due to deposited ^{137}Cs of more than 37 kBq/m^2 in areas of Belarus, Ukraine and Russia. The total area covered is about 131000 km^2 [29]. Doses to these persons resulted both from external exposures from the passing cloud and from radionuclides deposited on the ground or other surfaces and from internal exposures: inhalation of material from the passing cloud in the first days and ingestion of various radionuclides that contaminate foods.

Residents of 'strict control zones'

About 270000 people lived in the 10300 km^2 of the SCZs (with ^{137}Cs deposition activity density of more than 600 kBq/m^2 in 1986 (Table III). The collective doses to these populations have not recently been estimated explicitly. However, the dynamics of dose formation have been considered and reported in detail by Balonov and collaborators [29]. From this work, it can be estimated that the average external and internal dose during the period 1986 to 1995 for the population in these areas is approximately 50 μSv per kBq/m^2 of ^{137}Cs deposition density. For the SCZs, a reasonable estimate of the average deposition density is 25 Ci/km^2 (925 kBq/m^2): areas with deposition density greater than 40 Ci/km^2 (1480 kBq/m^2) were generally evacuated. Thus, an approximate value of the average effective dose is 50–60 mSv and the collective effective dose for the 270000 residents is 10000–20000 man.Sv.

Residents of other 'contaminated' territories

An estimate of the collective dose for the remaining 3.7 million persons living in 'contaminated' areas can be made in a similar fashion. The average deposition density is assumed to be 3 Ci/km^2 (111 kBq/m^2). The average external and internal dose during the period 1986–1995 for the population in these areas is approximately 50–150 μSv per kBq/m^2 of ^{137}Cs deposition activity density (higher than in the SCZs, as there were less strict controls on internal dose). The average effective dose is therefore calculated to be in the range 6–20 mSv. The estimate of collective effective dose is 20000–60000 man.Sv. This estimate is compatible with the more rigorously evaluated value of 22000 man.Sv by Kenigsberg et al. [31] for the entire population of Belarus. Their estimate for the average dose to the residents of the Gomel and Mogilev oblasts is 5.9 mSv. A comparable estimate of collective dose for the entire population of Ukraine is given by Likhtarev and Kovgan [33] as 47500 man.Sv, with about 15000 man.Sv calculated to be delivered to inhabitants of areas with a ^{137}Cs deposition activity density of less than 1 Ci/km^2 (37 kBq/m^2).

It should be noted that, given the large number of persons residing in these areas, small errors in dose estimates may lead to large errors in the collective dose. Thus, the predicted health effects discussed in the following for this population are very uncertain and should be treated with circumspection. Doses received early after the accident are not known clearly and, as discussed in Background Paper 5, there has been a general tendency to overestimate doses out of caution for radiation protection purposes.

Thyroid doses to populations in 'contaminated' regions

An early exposure situation of special interest is the thyroid dose to the general population living in the heavily contaminated regions of Belarus, Russia and Ukraine, owing to the current reports of major increases in the incidence of childhood thyroid cancer in all three countries [34–38]. As discussed in more detail in Background Paper 2 on thyroid effects, there is now very strong circumstantial evidence that this increase is related to the dose received from iodine isotopes early after the accident and is not related to any present exposure. Major efforts have been made, and are continuing, to reconstruct thyroid doses to the populations at risk. A summary of the results reported is provided in Background Paper 2.

3. DISCUSSION

3.1. Expected health consequences

This section presents predicted health effects, particularly cancer and hereditary disorders, derived from models of radiation induced risk developed from epidemiological studies of other populations exposed to radiation, mainly the survivors of the atomic bombing of Japan (Life Span Study, LSS). Although there are a number of epidemiological studies from which radiation risk data can be obtained, the studies of the survivors of the atomic bombing continue to be the main source of data for risk estimation [9, 26, 39, 40]. The survivors were exposed primarily externally and at high dose rates, however. Models must be used to extrapolate the effects of such exposures to exposures at the generally lower doses and lower dose rates that are of concern for the majority of populations owing to the Chernobyl accident. The assumptions underlying these models are inevitably subject to uncertainties. Major questions relate to the choice of models for transfer of data between populations with different background cancer rates, for projection of risk over time and for extrapolation of risks following primarily external high dose and high dose rate exposures to low dose and low dose rate exposures involving both external and internal radiation.

In the predictions presented here, the estimates for the survivors of the atomic bombing were applied directly to the populations exposed as a result of the Chernobyl accident, on the assumption that, for a given radiation dose, the resulting cancer risk is the same regardless of the pattern and type of exposure. It is noted that, in extrapolating the risk estimates based on high dose and high dose rate exposures to low dose and low dose rate exposures, the International Commission on Radiological Protection (ICRP) has used a reduction factor (the dose and dose rate effectiveness factor (DDREF)) of two [40].

3.1.1. Solid cancers and leukaemia

Lifetime risk estimates (through age 95 years) were computed for solid cancers and leukaemia (excluding chronic lymphocytic leukaemia) for the liquidators and the populations living in 'contaminated' areas of Belarus, Russia and Ukraine. The methods used follow those of the UNSCEAR 1994 Report [1], allowing for the modifying effects of age at exposure and sex (for leukaemia). Table IV presents the predictions of lifetime risk (numbers of deaths) from solid cancers and leukaemia. The number of deaths predicted in the first 10 years after the accident are also presented for leukaemia but not for solid cancers as in the model a 10 year latency period is assumed between an exposure and the resulting increase in cancer incidence.

For both solid cancers and leukaemia, the predicted proportions of excess deaths among all deaths from these diseases (i.e. the 'attributable fractions') are small. For solid cancers, they range from less than 1% among the populations evacuated from the 30 km zone and the residents of 'contaminated' areas outside the SCZs to about 5% for the liquidators who worked in 1986 and 1987. The lifetime attributable fraction for leukaemia is greater than that for solid cancers in each population, ranging from 2% to 20%. The fraction of excess leukaemia cases is much higher for the first 10 years.

3.1.2. Thyroid cancer in children

The projections of numbers of thyroid cancer cases were made for populations exposed as children, i.e. between the ages of 0 and 14, in the various oblasts of Belarus and in Bryansk oblast in Russia, for which both dose estimates and population data were available (Table V). Two sets of published data on the incidence of thyroid cancer were used to estimate the background (naturally occurring) incidence of thyroid cancer: the 1983–1987 Belarus incidence data and the 1983–1987 USA White (SEER) cancer incidence data [41]. The US incidence data were used because it was considered likely that the Belarus thyroid rates underestimate the true incidence, especially before the accident when the registry may not have been as active as afterward. The risk projections were made both for lifetime and for the first 10 years after the accident; in both cases a 5 year latent period is assumed.

The predicted lifetime excess number of cases ranges from 0.01% in Vitebsk oblast to about 1% in Gomel oblast using the incidence rates for the USA, while the attributable fraction ranges from 5% to 77%. The total number of cases expected in the oblasts of Belarus for the first 10 years after the accident varies between 39 and 128, depending on the baseline rates used.

3.1.3. Hereditary effects

The basic assumption made in estimating hereditary effects was that, in the first generation offspring of a population of 1000000 persons, including all ages and both sexes, 30 cases with hereditary disorders will be observed per 480000 births per 10 mSv to each parent [42]. The hereditary disorders considered here include autosomal dominant, X-linked, recessive, chromosomal and congenital abnormalities. The background (naturally occurring) hereditary disorders were estimated using the 1993 UNSCEAR Report. The projection model used here follows those of the US Nuclear Regulatory Commission Report [42] and provides the *upper limit* of the risk.

Results presented in Table VI show a very low predicted occurrence of radiation induced hereditary effects, ranging from 0% to 0.03% of all live births and from < 0.1% to 0.4% of all hereditary disorders among the live births to the exposed population.

3.2. Summary of available results

3.2.1. Cancer

Table VII presents the number of observed and expected cases of cancer in 1993–1994 among liquidators who had worked in the 30 km zone around the Chernobyl plant in 1986–1987, and among the populations in the three countries living in oblasts where some areas had ^{137}Cs activity levels above 185 kBq/m^2. The observed numbers of cancer cases were obtained from the National Cancer Registry in Belarus and from the State Chernobyl Registries in Russia and Ukraine. No information could be obtained systematically for evacuees and residents of the SCZs. The expected numbers are based on the general national population; in Belarus, they were also obtained from the Cancer Registry, while in Russia and Ukraine they are based on data from regional oncological dispensaries summarized annually at the national level. These results are adjusted for age and sex; for liquidators, they are restricted to men since the majority of exposed liquidators were men.

Liquidators

There was no increase in the incidence of cancers as a whole among liquidators in comparison with that for the general population in Belarus. In Russia, a small but marginally statistically significant increase was noted among liquidators, of the order of 11%. There was no consistent difference in the incidence of specific types of cancer in Belarus or Russia among the liquidators and among the general population.

In Ukraine, a 20% increase in the incidence of all cancers among liquidators was observed, as well as increases in the incidence of several specific cancer types. As discussed in Section 2.2.2, these results must be treated with caution, since the cases have not yet been verified and the increase may reflect the effect of increased surveillance of the liquidators and previous underregistration of cases in a country where no systematic centralized cancer registry existed at the time of the accident [43].

A total of 46 leukaemia cases were reported among the liquidators in the three countries during the two year period. A non-significant twofold increase (based on nine observed cases) was observed in Belarus. In Russia, there was no significant difference in leukaemia incidence among liquidators in comparison with the general population. In Ukraine, a significant increase in leukaemia incidence was observed; it must be treated with caution for the reasons already stated.

An increase in the incidence of thyroid cancer was noted in all three countries, based on relatively small numbers of cases (28 cases in 1993–1994). Significant radiation doses to the thyroid may have been received from short lived iodine isotopes by the liquidators who worked in the 30 km zone in the first days after the accident. The data, however, have not yet been analysed according to the time of work in the 30 km zone; information about the histology of the tumours and their mode of confirmation is also not yet available. This result must therefore be interpreted with caution, especially since the follow-up of liquidators is much more active than that of the general population in the three states: for thyroid cancer in adults, the depth of screening may greatly influence the observed incidence [44, 45].

Residents of 'contaminated' areas

No increase was observed in the incidence of all cancers in Ukraine. In Russia and Belarus, a marginally statistically significant 3% increase in all cancer mortality was noted, while no increase was observed for leukaemia in any of the three countries. For thyroid cancer, a 1.5- to 2-fold increase was seen in the three countries. Again, because of increased awareness of the consequences of the accident, and because of the more intensive medical follow-up of populations living in more contaminated regions, these findings must be interpreted with caution, and further analyses are needed to confirm or refute this finding.

A number of authors have recently reported increasing trends in cancer morbidity over time in the populations living in 'contaminated' territories [43, 46]. Care must be taken in interpreting these findings, particularly in countries where no centralized cancer registration exists and for cancer types for which increased ascertainment may result in an apparent increase in incidence. Prisyazhniuk and collaborators [43] have analysed trends in cancer morbidity in the 'contaminated' territories of Belarus, Russia and Ukraine. Although they observed increases in the incidence of all cancers and of leukaemia, they noted that this increase was consistent with pre-existing increasing trends in the incidence of these diseases. The increases were, moreover, not related to the levels of exposure in the regions. The predominant difference with pre-accident rates was noted for cancers in the oldest age group considered (65 years and over), which started as early as one year after the accident. This most likely reflected increased ascertainment of diseases in this population. For leukaemia, the increase primarily concerned chronic lymphocytic leukaemia, a subtype not seen to be associated with radiation exposure in other studies.

Background Paper 2 describes the distribution of number of cases and incidence of childhood thyroid cancer in the 'contaminated' regions of the three countries since the accident. As indicated in that paper, a dramatic increase has been observed in 'contaminated' territories of Belarus, Ukraine and, more recently and to a more limited extent, in Russia. The circumstantial evidence that this increase is related to iodine isotopes released as a result of the accident is very strong. A number of questions remain to be answered, however. In particular, the observation of such a large increase in the incidence of a very rare cancer in children raises the possibility that host and environmental factors may modify the risk of cancer induction due to radiation exposure.

3.2.2. General morbidity

A number of authors have considered the general morbidity of liquidators in the affected countries and compared it to that of the general population in these countries (see for example Refs [23, 46, 47]). Apparent increases in the morbidity for a number of broad disease classes (diseases of the endocrine system, diseases of the blood and blood forming organs, mental disorders, diseases of the circulatory and digestive systems) have been reported. It is difficult to interpret these results. These observations may at least partly be explained by a bias introduced by the active follow-up of liquidators and by the impossibility of taking into account the influence of age and sex in the analyses (see Sections 2.2.1 and 2.2.2). On the other hand, they may reflect a real increase in morbidity following the Chernobyl accident. If so, on the basis of existing epidemiological studies of radiation exposed populations, it is unlikely that they are related to the radiation exposure, although they could be related to stress and economic difficulties following the accident (see Background Paper 4).

3.2.3. General mortality

Recent reports indicate an increase in mortality rates (accompanied by a decrease in the average lifespan) in states of the former USSR [48]. These increases, which do not appear to be related to radiation exposure, since the pattern does not differ between regions with different levels of contamination, may again be related to social and economic difficulties (see Background Paper 4). They must, however, be taken into account in interpreting time trends in exposed populations.

3.3. Comparisons with expected effects

3.3.1. Leukaemia

On the basis of the data from other populations exposed to radiation, the major radiological impact expected to date (i.e. within the first 10 years after the Chernobyl accident), if the experience of the survivors of the atomic bombing is applicable, is leukaemia.

As indicated in Table IV, the increase is mainly expected among liquidators; indeed, out of 190 cases of leukaemia expected in the first 10 years among 200000 liquidators, 150 (79%) would be expected to have been induced by radiation exposure as a result of the accident. Such an increase can be detected epidemiologically. No consistent increase has been reported to date. The results reported in Section 3.2.1 concern only a two year period, however, and the power to detect such an increase is thus much reduced.

The expected increase in leukaemia incidence in the first 10 years after the accident in the SCZs and in the 'contaminated' areas is much lower than among liquidators: of the order of 1.5-fold and 1.05-fold, respectively. This is consistent with the fact that no increase in leukaemia incidence was observed among residents of 'contaminated' regions in the three countries. Indeed, such increases would be very difficult to detect epidemiologically.

3.3.2. *All cancers*

If risk models from other studies of populations exposed to ionizing radiation are applicable, no increase in the incidence of all cancers should be detectable to date. The findings of a 10–20% increase among liquidators in Russia and Ukraine and a 3% increase in the populations residing in 'contaminated' regions in Belarus and Russia, particularly in the absence of a consistent increase in leukaemia incidence in these populations, are therefore not consistent with predicted effects.

The increases observed may be real. They may also, however, be an artefact of the above mentioned differences in the follow-up of disease between exposed populations and the general population of the affected countries (see Section 2.2).

3.3.3. *Thyroid cancer*

The number of thyroid cancer cases expected for the first 10 years after the accident among persons exposed to iodine isotopes during childhood is presented in Table VI. The discrepancies between the projected numbers based on the background data for Belarus and observed numbers (see Background Paper 2) are outstanding. When the USA background rates for whites are used, however, the discrepancies are less pronounced. The notable exception is the Gomel population, which shows a remarkably higher number of cases observed than expected.

It should be noted that our predictions include cases who were adolescents and even young adults at the time of diagnosis. The predicted number of cases diagnosed among children would be about half. Since the numbers presented in Background Paper 2 refer only to cases who were children not only at the time of the accident but also at diagnosis, the discrepancy is even larger than it appears. (However, the uncertainties in the estimated doses for the period early after the accident should be borne in mind.)

4. FUTURE PROSPECTS

If the experience of survivors of the atomic bombing and of other exposed populations is applicable, the total lifetime numbers of excess cancers will be greatest among the liquidators and among the residents of 'contaminated' territories, of the order of 2000 to 2500 in each case. These increases, however, would be difficult to detect epidemiologically against an expected background number of 41500 and 433000 respectively.

Predictions based on other exposed populations, and preliminary results to date, indicate that the significant health effect most likely to be detected at this time and in the future, besides thyroid cancer, is leukaemia among liquidators. Indeed, if careful large scale studies of liquidators are carried out, they not only ought to have sufficient power to detect an increased risk, but may provide important information concerning the effects of exposure protraction and perhaps of radiation type in the relatively low dose (0–500 mSv) range.

The extent of the increase in thyroid cancer is very difficult to predict, as the observed incidence in those exposed as children is, particularly in the Gomel area of Belarus, considerably greater than would have been expected on the basis of past studies. Background Paper 2 discusses the predictions in more detail. Uncertainties mainly concern dose estimates; the temporal behaviour of the increase; if the relative increase stays constant over time, a very large increase in the incidence of thyroid carcinoma may be observed in the next century in adults who were exposed as children.

An increase in the incidence of thyroid cancer in adults (liquidators and populations residing in 'contaminated' territories) has also been reported in recent years. At present, however, this increase needs verification, and it is unclear whether it is related to exposure from the Chernobyl accident or to changes in the ascertainment of this disease due to more active follow-up of exposed populations. Predictions of thyroid cancer risk in those exposed as adults are therefore very uncertain.

Because of the absence of established population based registries in the affected countries (and in most countries), it is difficult to monitor trends in hereditary effects. Given the levels predicted, however, it is unlikely that, if data from other studies are applicable, any increase could be detected in the offspring of the exposed populations.

As indicated in Section 2.2.2, a number of factors limit the power of the routine follow-up activities listed earlier to detect the expected effect of radiation exposure due to the Chernobyl accident, even in the three most affected countries. They include, in particular, the generally low level of radiation dose received by the majority of exposed populations, and hence, presumably, low level of risk expected, the difficulties of systematic and complete active follow-up, the lack of precise dosimetry, and the important movements of populations that have taken place since the accident.

Ad hoc analytical epidemiological studies, focusing on specific diseases and populations, may be a more useful approach to investigating the effects of radiation exposure among the exposed populations. Both cohort and case control studies are generally much more powerful than descriptive studies for investigating dose relationships. To be informative, however, studies of the consequences of the Chernobyl accident must fulfil several important criteria: they must cover very large numbers of exposed subjects; the follow-up must be complete and non-selective; and precise and accurate individual dose estimates (or markers of exposure) must be available. In particular, the feasibility and the quality of epidemiological studies largely depend on the existence and the quality of basic population based registers, and on the feasibility of linking information on a single individual from different data sources.

Studies of leukaemia and thyroid cancer risk among liquidators are now under way or planned in all three countries. They are designed as cohort studies, and in some cases as case control studies (since pilot studies have shown that cohort studies of these populations would require substantial financial and human resources). Given the distribution of known doses among the liquidators, the power of such studies in individual countries is relatively low, however, and it is essential that studies carried out in different affected countries be similar so that the results can ultimately be compared and combined. Dosimetry still poses an important problem, as dose estimates are missing and of uncertain quality for a substantial proportion of the liquidators in the three countries. Efforts are being made to estimate radiation levels from detailed questionnaires of activities conducted in the Chernobyl area. If these conditions are met, studies of liquidators will provide important information concerning the effects of exposure protraction and perhaps of radiation type in the relatively low dose (0–500 mSv) range.

Non-specific studies of cancer risk among the general population exposed in the 'contaminated' regions are unlikely to be informative for radiation risk estimation because of the generally lower doses received by the majority of these populations, and the difficulties in estimating these doses and in following these populations. An exception is the study of thyroid cancer risk in populations exposed as children, the incidence of which has been observed to increase dramatically in the first years following the accident. Careful cohort and case control studies are under way and planned in all countries. They may provide important information on the risk of induction of thyroid cancer due to radiation exposure, as well as a unique opportunity to increase our understanding of factors that modify the risk of induction of cancer due to radiation exposure and thus have important consequences for the radiation protection of patients and the general population.

The predictions described here were made using risk models derived from studies of the survivors of the atomic bombing. As discussed earlier, models must be used to extrapolate the effects of such exposures to the generally lower dose and lower dose rate exposures and for the radiation types of concern for the majority of populations exposed as a result of the Chernobyl accident. These models are, inevitably, subject to uncertainties. Indeed, although an increase in the incidence of thyroid cancer in persons exposed as children as a result of the Chernobyl accident was envisaged, the extent of the increase was not foreseeable. It is essential therefore that monitoring of the health of the population be continued in order to assess the public health impact of the accident, even if, given the level of the dose received, little detectable increase of cancers due to the Chernobyl accident is expected except in liquidators.

As discussed earlier, although 10 years have passed since the Chernobyl accident, results published to date are difficult to interpret, mainly because of differences in the intensity and method of follow-up between exposed populations and the general population with which they are compared. In order for results of such monitoring in the future to be unambiguous, it is important that they are based on systematic and complete population based registries, in particular registries of mortality and of cancer. Russia and Ukraine currently lack national population based cancer registries. It is therefore important for monitoring that such registries be established (at least in the 'contaminated' regions in Russia) or improved, where appropriate. Such registries will be useful, not only for assessing the public health impact of the Chernobyl accident, but also for other activities in research and in planning and monitoring for public health in these countries.

5. CONCLUSIONS

Ten years after the Chernobyl accident, the dramatic increase in thyroid cancer in those exposed as children in the three most affected countries is the only evidence to date of a public health impact of radiation exposure as a result of the Chernobyl accident. Any increase in the incidence of all cancers, or in mortality, attributable to radiation exposure due to the accident has not been statistically detectable. In particular, no attributable increase has been detected in rates of leukaemia – even among liquidators – one of the major concerns after radiation exposure. This is generally consistent with predictions based on studies of other radiation exposed populations, in particular the survivors of the atomic bombing.

Increases in thyroid cancer among those exposed as children were observed in the more heavily contaminated regions of Belarus, Ukraine and Russia, at rates much higher than predicted from previous studies. These increases, which are discussed in more detail in Background Paper 2, may reflect either particular sensitivity of the population, due to host or environmental factors; or underestimation of doses to the thyroid (possibly due to uncertainties in the estimated doses for the period early after the accident); or the high carcinogenic potential of very short lived iodine isotopes. Increases in thyroid cancer are now also reported among liquidators and the general population; these must, however, be verified before they can be attributed to the Chernobyl accident. There is a tendency to automatically attribute fluctuations and/or increases in cancer rates over time to the Chernobyl accident. It should, however, be noted that increases in the incidence of some neoplasms have been observed in some countries in the last decades, prior to the accident. A general increase in mortality has, moreover, been reported in recent years in many areas of the former USSR which does not appear to be related to radiation levels. This must be taken into account when interpreting the results of studies.

Increases in the frequency of a number of non-specific detrimental health effects other than cancer among exposed populations, particularly among liquidators, have been reported. It is difficult to interpret these findings because exposed populations undergo a much more intensive and active health follow-up than the general population. If real, these increases may be attributable to stress and to anxiety resulting from the accident; they are discussed in Background Paper 4.

Only ten years have passed since the accident, and on the basis of epidemiological studies of other populations, any increases in the incidence of cancers other than leukaemia are usually not visible until at least ten years after exposure. It is noted that the exposures of the public as a result of the Chernobyl accident are different (in type and pattern) from those of the survivors of the atomic bombing. Predictions derived from these populations are therefore uncertain and it is essential to continue monitoring the health of the exposed populations through population based disease registries.

Studies of selected populations are also needed in order to study observed or predicted effects; careful studies may in particular provide important information on the effect of exposure rate and exposure type in the low to medium dose range and on factors which may modify radiation effects. As such, they may have important consequences for the radiation protection of patients and for the general population in the event of accidental exposures.

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TABLE I. ESTIMATES OF COLLECTIVE EFFECTIVE DOSES FOR POPULATION GROUPS OF INTEREST

Population	Number	Collective effective dose (man.Sv)
Evacuees	135 000	1 300
Liquidators (1986–1987)	200 000	20 000
Persons living in 'contaminated' areas[a]:		
Deposition density of ^{137}Cs >15 Ci/km^2	270 000	10 000–20 000
Deposition density of ^{137}Cs >1 to 15 Ci/km^2	3 700 000	20 000–60 000

[a] These doses are for 1986–1995; over the longer term (1996–2056), the collective dose will increase by approximately 50%. 1 Ci/km^2 is equivalent to 37 kBq/m^2.

TABLE II. DISTRIBUTION OF LIQUIDATORS BY DOSES IN THE THREE MOST AFFECTED STATES

	Number of liquidators	Dose (mGy)				
		Percentage of doses known	Mean	Median	75% percentile	95% percentile
Belarus						
1986–1989	63 000	13.8%	43.0	23.5	67.3	119
1986–1987, 30 km zone	31 000	28.4%	39.1	20	67	111
Ukraine						
1986–1987	102 000	N.A.[a]	N.A.	N.A.	N.A.	N.A.
Sample studied	*15 700*	*51.9%*	*163.4*	*134.3*	*N.A.*	*N.A.*
Russia						
1986–1989	148 000	63.2%	106.6	92	180.3	240
1986	69 000	50.8%	168.7	194	220	250
1987	53 000	70.5%	91.6	92	100	208
1988	20 500	82.5%	34.0	26	45	94
1989	6 000	73.0%	31.6	29.5	48	52

[a] Not available.

TABLE III. DISTRIBUTION OF POPULATION LIVING IN TERRITORIES WITH ^{137}Cs ACTIVITY DENSITY ABOVE 555 kBq/m^2 IN 1986 (FROM ILYIN ET AL. [27])

	Size of population in 1986
Belarus	~ 106 000
Russia	~ 111 800
Ukraine	~ 52 000
Total	~ 270 000

TABLE IV. PREDICTIONS OF BACKGROUND AND EXCESS DEATHS FROM SOLID CANCERS AND LEUKAEMIA IN POPULATIONS EXPOSED AS A RESULT OF THE CHERNOBYL ACCIDENT

Population	Population size/ average dose (mSv)	Cancer type	Period	Background number of cancer deaths		Predicted excess		
				Number	Per cent	Number	Per cent	AF[3]
Liquidators, 1986–87	200 000	Solid cancers	Lifetime (95 years)	41 500	21%	2 000	1 %	5 %
	100 mSv	Leukaemia	Lifetime (95 years)	800	0.4 %	200	0.1 %	20 %
			First 10 years	40	0.02 %	150	0.08 %	79 %
Evacuees from 30 km zone	135 000	Solid cancers	Lifetime (95 years)	21 500	16 %	150	0.1 %	0.1 %
	10 mSv	Leukaemia	Lifetime (95 years)	500	0.3 %	10	0.01 %	2 %
			First 10 years	65	0.05 %	5	0.004 %	7 %
Residents of SCZs	270 000	Solid cancers	Lifetime (95 years)	43 500	16 %	1 500	0.5 %	3 %
	50 mSv	Leukaemia	Lifetime (95 years)	1 000	0.3 %	100	0.04 %	9 %
			First 10 years	130	0.05 %	60	0.02 %	32 %
Residents of other 'contaminated' areas	3 700 000	Solid cancers	Lifetime (95 years)	433 000	16 %	2 500	0.05 %	0.6 %
	7 mSv	Leukaemia	Lifetime (95 years)	13 000	0.3 %	200	0.01 %	1.5 %
			First 10 years	1 800	0.05 %	100	0.003 %	5.5 %

[3] AF: attributable fraction = excess deaths / total deaths from the same cause.

TABLE V. PREDICTIONS OF BACKGROUND AND EXCESS CASES OF THYROID CANCER AMONG PERSONS EXPOSED TO IODINE ISOTOPES DURING CHILDHOOD (0–14 YEARS) AS A RESULT OF THE CHERNOBYL ACCIDENT: BACKGROUND INCIDENCE RATES: BELARUS AND WHITE POPULATION OF THE USA FROM 1983–1987 [41].

Population	Population size/ average dose (mSv)	Period	Background incidence	Background number of cancers		Predicted excess			Total expected to 1996
				Number	Per cent	Number	Per cent	AF[4]	
Belarus									
Brest oblast	377 000	Lifetime (95 years)	Belarus	452	0.12%	132	0.04%	23%	
			US white	1 300	0.34%	380	0.10%	23%	
	30 mSv	First 10 years	Belarus	6	0.00%	<1	0.00%	5%	6
			US white	18	0.00%	1	0.00%	5%	20
Vitebsk oblast	361 000	Lifetime (95 years)	Belarus	432	0.12%	22	0.01%	5%	
			US white	1 250	0.35%	50	0.01%	4%	
	5 mSv	First 10 years	Belarus	5	0.00%	<1	0.00%	5%	5
			US white	18	0.00%	1	0.00%	5%	18
Gomel oblast	403 000	Lifetime (95 years)	Belarus	438	0.11%	1495	0.37%	77%	
			US white	1 400	0.35%	4300	1.07%	75%	
	290 mSv	First 10 years	Belarus	6	0.00%	5	0.00%	45%	11
			US white	20	0.00%	17	0.00%	46%	36
Grodno oblast	302 000	Lifetime (95 years)	Belarus	362	0.12%	53	0.02%	13%	
			US white	1 050	0.35%	150	0.05%	13%	
	15 mSv	First 10 years	Belarus	4	0.00%	<1	0.00%	6%	4
			US white	15	0.00%	1	0.00%	6%	15
Minsk oblast	399 000	Lifetime (95 years)	Belarus	478	0.12%	104	0.03%	18%	
			US white	1400	0.35%	300	0.08%	18%	
	20 mSv	First 10 years	Belarus	6	0.00%	<1	0.00%	5%	6
			US white	20	0.01%	1	0.00%	5%	20

[4] AF: attributable fraction = excess deaths / total deaths from the same cause.

Population	Population size/ average dose (mSv)	Period	Background incidence	Background number of cancers		Predicted excess			Total expected to 1996
				Number	Per cent	Number	Per cent	AF[4]	
Mogilev oblast	294 000	Lifetime (95 years)	Belarus	352	0.12%	350	0.12%	50%	
			US white	1 000	0.34%	1 000	0.34%	50%	
	90 mSv	First 10 years	Belarus	4	0.00%	1	0.00%	20%	5
			US white	14	0.00%	4	0.00%	22%	19
All Belarus oblasts	2 140 000	Lifetime (95 years)	Belarus	2 558	0.12%	2 157	0.10%	46%	
			US white	7 400	0.35%	6 200	0.29%	46%	
	80 mSv	First 10 years	Belarus	31	0.00%	7	0.00%	18%	39
			US white	105	0.00%	24	0.00%	19%	128
Russian Federation									
Bryansk oblast	92 000	Lifetime (95 years)	Belarus	110	0.12%	42	0.05%	28%	152
			US white	300	0.33%	120	0.13%	29%	420
	35 mSv	First 10 years	Belarus	1	0.00%	<1	0.00%	50%	2
			US white	5	0.01%	<1	0.00%	<20%	5

TABLE VI. PREDICTIONS OF BACKGROUND AND EXCESS NUMBERS OF HEREDITARY DISORDERS IN POPULATIONS EXPOSED AS A RESULT OF THE CHERNOBYL ACCIDENT

Population	Population size/ average dose (mSv)	Total live births	Total background cases with hereditary disorders		Total cases with radiation related hereditary disorders		
			Number	Per cent	Number	Per cent	AF[5]
Liquidators 1986–1987	200 000 100 mSv	250 000	19 000	7.60%	80	0.03%	0.42 %
Evacuees from 30 km zone	135 000 10 mSv	65 000	5 000	7.69%	5	0.01%	0.10 %
Residents of SCZs	270 000 50 mSv	130 000	10 000	7.69%	40	0.03%	0.40 %
Residents of other 'contaminated' areas	3 700 000 7 mSv	1 800 000	137 000	7.61%	80	0.00%	0.06 %

[5] AF: attributable fraction = excess deaths / total deaths from the same cause

TABLE VII. STANDARDIZED INCIDENCE RATIO (SIR) FOR ALL CANCERS (ICD 9 CODES 140-208) AMONG MALE LIQUIDATORS WHO WORKED IN THE 30 km ZONE IN 1986–1987 AND AMONG RESIDENTS IN OBLASTS WITH 'CONTAMINATED' AREAS (> 185 kBq/m^2), IN COMPARISON WITH INCIDENCE FOR THE GENERAL NATIONAL POPULATION: FOR THE PERIOD 1993–1994

All cancers	Observed	Expected	SIR	95% confidence interval
Male liquidators				
Belarus	102	135.6	75	61–91
Russia	449	404.7	111	101–121
Ukraine	399	329	121	109–133
Population in 'contaminated' territories				
Belarus	9 682	9 387	103	101–105
Russia	17 260	16 800	103	101–104
Ukraine	22 063	22 245	99	98–101