Strategic Research Agenda

The Health Consequences of the Chernobyl Accident

Executive Summary

With the support of the European Commission, an international group of experts and advisors formed the project "ARCH: Agenda for Research on Chernobyl Health" to review the health consequences of exposure to radiation from the Chernobyl accident and provide advice on the studies needed to be carried out in the future. The current document is ARCH's proposal for a Strategic Research Agenda (SRA), outlining a reasoned long-term plan for research into the health consequences of radiation from the Chernobyl accident.

There are several main reasons why even now, over 20 years after the accident it is important that the European Commission supports a long-term coordinated research programme on the health effects of the Chernobyl accident. Health effects from this European accident continue and future effects are uncertain. Past knowledge of radiation effects is largely based on atomic bomb studies, but Chernobyl involved a very different type of exposure. Assumptions on the risk of low dose exposure have been challenged by recent advances in radiobiology. Estimates of deaths due to the Chernobyl accident vary widely.

The ARCH group of experts and advisors therefore support proposals for the long term funding of a Chernobyl Health Effects Research Foundation, similar to the action taken to create the Radiation Effects Research Foundation some years after the atomic bomb exposures in Japan, together with a series of individual studies covering the main health consequences. These include the ongoing thyroid cancer problem, the reported rise in breast cancer, inherited molecular-genetic alterations, and various cancers, cataracts and other non-cancer diseases in liquidators and in the general exposed population. Long-term studies of already existing groups with known radiation doses would provide invaluable information on the life-time risks of both external and internal exposure.

Unless coordinated studies are set up, together with a mechanism to ensure long-term funding, the long-term consequences of a nuclear accident involving the exposure of many millions of people to radiation will not be properly studied, speculation will flourish, and knowledge essential to assessing the risks of radiation exposure will be lost.

Introduction

Chernobyl was by far the world's worst nuclear accident. Fallout from the accident spread across Europe and the Northern Hemisphere, with the result that the word "Chernobyl" has an iconic status among the general public. Millions of the general population were exposed to radiation from fallout. They and hundreds of thousands of the clean-up workers (liquidators) were exposed to a variable mixture of external and internal radiation. The exposed populations still show Chernobyl-related effects today, however the magnitude of health effects up to the present are disputed and because of the unique nature of the accident future effects cannot be accurately predicted.

This document sets out in general terms a long-term Strategic Research Agenda (SRA) to maximise the lessons which can be learnt from Chernobyl. A new initiative to ensure the effective implementation of this SRA is also proposed.

The SRA is based on a detailed review by the ARCH group of experts and advisors from the EC, the countries close to Chernobyl, USA, and Japan (names listed in the Appendix). The group has given close consideration to the relevance of Chernobyl studies to radiation protection, carcinogenesis and public health, and to the importance of recent advances in radiobiology which question current assumptions on the risks of low dose exposure.

The experts and advisors strongly support the need for well-designed and coordinated long-term studies. Reliable information on the health effects of Chernobyl is extremely important for sociological, scientific and health protection reasons. The consequences of the accident are ongoing and it is difficult to predict what future effects will occur in those exposed and in their offspring. After the explosions of the atomic bombs in Hiroshima and Nagasaki a long-term comprehensive study of the health effects was set up jointly by the USA and Japan (1). The ARCH Expert Group recommends that a comparable international study of the effects of Chernobyl should be set up as soon as is possible. Unless this is done the overall consequences of this iconic event will never be known with certainty, speculation will be rife, and information of great importance for science and human health will be irretrievably lost.

Background

The Chernobyl accident occurred on the 26th of April 1986; it was and remains by far the most serious nuclear accident in the history of nuclear power with releases to the environment of huge quantities of radioactive material. The health consequences of the accident are controversial. The wide discrepancy between reports, including those published in peer-reviewed journals, causes public confusion over radiation risks and the safety of nuclear power; the lack of consensus prevents possibly critical changes in radiation protection standards. Current understanding of the consequences of radiation exposure is largely based on comprehensive studies carried out on the survivors of the atomic bombs in Japan, where the population was exposed to instantaneous whole body external radiation from gamma rays and neutrons. In contrast, the Chernobyl accident exposed millions of people to protracted external and internal beta and gamma radiation. The consequences of Chernobyl could therefore differ markedly from those of the atomic bombs: the type of radiation differed, the tissue dose distribution differed, and the length of exposure differed, as did the genetic makeup of the population.

Among the general population exposed to fallout from the Chernobyl accident, the main health consequence of radiation exposure demonstrated to date is an increased risk of thyroid cancer following exposure to fallout in childhood (2;3). The increase was much greater and with a much shorter latency than had been expected. Studies have shown that the risk is highest in those exposed as young children: they carry their risk of developing thyroid cancer into adult life. Nearly all thyroid carcinomas have been of papillary type (PTC), and the clinical, morphological and molecular features of these tumours have changed with time since exposure (4). It is now clear that the initial findings of clinically aggressive solid variant PTCs with specific oncogene (RET-PTC3) rearrangements thought to be typical of radiation induced tumours were in fact typical of short latency tumours. More than 5,000 cases of thyroid cancer are reported in young people since the Chernobyl accident; while not all are related to radiation, a large majority are. The increased incidence continues to occur and further changes are likely (3).

The research focus on the large increases in thyroid cancer incidence has meant that attention to other possible consequences has been limited. A possible increase in breast cancer incidence has recently been detected (5). There have been reports of an increase in the incidence of childhood leukaemia in those exposed to fallout, but this is disputed (3). Increases in incidence of a variety of other tumours and in cardiovascular diseases have been claimed but not substantiated (3).

Among the liquidators, 134 cases of acute radiation sickness were diagnosed in those working on the site in the early phase of the accident, 28 died within the first four months. The survivors of those who received relatively high doses have shown increases in cataracts, leukaemia and other malignancies (6). Recent reports on lens opacities among Chernobyl clean-up workers (7) show that there is still uncertainty about the stochastic or deterministic nature of radiogenic cataracts. They suggest that radiogenic cataracts can occur at lower dose levels than believed previously.

Learning disability in children who were exposed *in utero* has been reported (8;9). Other possible effects of *in utero*/preconception exposure include reports of an increase in Down's syndrome, variation in the sex ratio of offspring, and the finding of DNA changes in children derived from minisatellite instability in the germ cells of their exposed fathers (10-12).

The psychosocial effects which have occurred in the population exposed to Chernobyl fallout are of major importance; although these were not included in the remit of the current study, the structure proposed would greatly facilitate further work in this area.

Dosimetry registers are maintained in the three most affected countries; the techniques of measurement and dose reconstruction may differ and dose values obtained with the use of these techniques are therefore difficult to compare. Biological dosimetry has only marginally contributed to Chernobyl studies due to lack of sensitivity.

A Chernobyl tumour bank was created and is maintained for thyroid tumours only. The potential for assessing cancer trends after the Chernobyl accident through existing cancer registries, particularly in Belarus and Ukraine, has not been fully exploited.

Apart from the minisatellite studies, little work has been carried out on the role that genomic instability and the bystander effect (13;14), relatively recently discovered radiation induced changes, may play in Chernobyl health effects.

The current overall picture is one of a series of uncoordinated studies, valuable in themselves but forming a patchwork rather than a comprehensive, structured attempt to delineate the overall health consequences of the accident.

Objectives of the SRA

The main goal of the SRA is to ensure that the health effects, short and long-term, of the Chernobyl accident are comprehensively studied. This will allow:

- better planning for health improvement of those exposed after Chernobyl,
- accurate information on the consequences of the Chernobyl accident to replace the present ubiquity,
- informed health planning for prevention and care for those exposed after future accidents,
- collection of information important for radiation protection measures and
- improved understanding of radiation effects, particularly the relationship between low dose exposures and health effects.

These aims will not be achieved unless a mechanism is created which can maintain an overview of Chernobyl research, encourage coordination and collaboration between existing research groups, and support research in critical areas.

Action needed to meet the objectives

Chernobyl provides direct evidence of the consequences of a major nuclear accident and it may not be the last. As argued above, there is a need to turn this experience into an opportunity to advance radiation research in order to maximize health protection during routine operations, minimize exposures during emergencies, and advance knowledge of the underlying science. To profit fully from the Chernobyl experience there must be an appropriate research infrastructure. The outstanding success of the studies of the atomic bomb survivors is largely due to the creation of the Lifespan cohort and the infrastructure associated with the Radiation Effects Research Foundation (RERF). The initial studies after the atomic bombs were, like those after Chernobyl, uncoordinated and far from comprehensive, and it was not until about 10 years later that, on the recommendation of the Francis committee, the necessary infrastructure for life time studies was created.

The Expert Group recommends that the EC should take the initiative in creating a Chernobyl Health Effects Research Foundation (CHERF) , with the following aims:

- **(a) to initiate and support the conduct of comprehensive research on the health effects of the Chernobyl accident,**
- **(b) to provide and disseminate an accurate unbiased assessment of the long-term consequences of the Chernobyl accident,**
- **(c) to inform radiation protection organisations of the short and long-term consequences of the Chernobyl accident relevant to radiation protection standards,**
- **(d) to deepen scientific understanding of the interaction of radiation with tissue, with special attention to internal exposures,**
- **(e) to provide public health organisations with the information needed to mitigate the consequences in the event of any similar exposure to radiation.**

Organisation and funding

The studies of the atomic bomb survivors, with consequences still occurring 60 or more years after exposure, are organised by the RERF which is jointly funded by the Japanese and US Governments, currently on approximately a 60/40 basis. To meet the need for comprehensive long-term studies with similar aims to those of the RERF a Chernobyl Health Effects Research Foundation (CHERF) should be set up. CHERF could be a virtual institute consisting of a

Management Board with representatives of the funding organisation(s) and the countries most involved, both inside and outside the EU, and a **Scientific Advisory Board** which can use the ARCH strategic agenda to help determine priorities for funding and advise the Management Board on projects that should be supported. Particular attention should be paid to long-term maintenance of the life-span cohorts needed to support a range of studies. CHERF should be subjected to four-yearly external review by international advisors in the field but not receiving grant support for Chernobyl studies. This review would take into account the dissemination of outcomes of the work supported and the adequacy of the research strategy. The reviewers together with the Scientific Advisory Board should consider the results obtained in the light of the overall risk assessment and suggest priorities for research which may be applicable to Chernobyl and other studies.

Discussions with the governments outside the EU will be needed, especially with the three most affected countries (Belarus, Ukraine and the Russian Federation), as well as Japan and the US, to set up a joint funding mechanism. Finalising a joint funding agreement could take a considerable time, and it is important for the EC to show its commitment by providing funding that will allow joint work to start with individual agreements. Because of the unique nature of the problem, the unique resource available, and the need for long-term support, the Expert Group recommends that there should be a separate funding mechanism, distinct from the Framework Programme, with an annual budget which will support the creation and study of the lifespan cohorts for an initial 10 years.

To meet the key aims, the Expert Group recommends that the following Chernobyl lifespan cohorts should be supported through CHERF:

a) *Liquidator cohort*. Their exposure was largely to the whole body, but at a much lower dose rate than after the atomic bombs. The numbers (over 600,000) are much greater than in the atomic bomb survivors Life Span Study (89,000), so that a large cohort with a wide range of low to moderate doses could be formed from existing liquidator cohorts, making it a population which is likely to be most informative, with great statistical power, for the study of cancer and non-cancer effects in adults at exposure. Liquidator registries are maintained in Belarus, the Russian Federation, Ukraine and in the Baltic countries; dose information is available for the majority but needs validation.

b) *Children at exposure cohort*. Millions of children were exposed to fallout after Chernobyl, but only for a minority is individual dose information available. However, a cohort of approximately 25,000 children from Belarus and Ukraine with detailed thyroid dose measurements has been collected as part of the BelAm and UkrAm projects with the original intent of following thyroid diseases only (15;16). With the appropriate cooperation and support this cohort could provide the basis for a long-term study of the cancer and non-cancer consequences of exposure to radiation from fallout.

The Expert Group recommends that CHERF should explore the feasibility of setting up other potentially important cohorts: *a cohort of offspring of liquidators* so that inherited effects can be studied and *a cohort of evacuees* (in particular children exposed directly or *in utero*) who were exposed internally to very high levels of fallout.

The creation of the appropriate lifespan cohorts proposed above requires not only long-term financial support but also the support and cooperation of the Governments and of the leading scientists and doctors in the most affected countries, as well as appropriate ethical permission. For the cohort of those exposed to fallout as children based on BelAm and UkrAm studies, and for the cohort of liquidators the relevant individuals and their doses are known or can be reconstructed, but follow-up is established separately in the different countries. Coordination and support for these studies are needed.

The Expert Group also recommends that *a tissue bank* be created or the existing thyroid tissue bank extended, to keep tumour and normal tissue and blood samples from the cohort studies, and make these available for future research studies. The bank could also preserve nucleic acids and immortalized lymphocytes from families with exposed parents and unexposed children to allow study of inherited effects.

Finally, to ensure that valuable information from the Chernobyl experience is not lost, the Expert Group emphasizes that **coordinated and long-term efforts are urgently needed**. Although nearly 25 years have passed, it is still not too late to form a 'Chernobyl Life Span Cohort' as many important diseases, both cancer and non-cancer, have such long latent periods that the outcomes are expected for years to come. As the Chernobyl accident happened in Europe, Europe should take the leadership in coordinating these long-term studies.

Early prediction of health effects after Chernobyl

In 1986, when the accident occurred, there was general confidence that the effects of exposure to ionising radiation could be predicted on the basis of past epidemiological studies of exposed populations, especially the atomic bomb studies, and a theoretical understanding of the biological bases of the action of ionising radiation. The fatal cancer risk was predicted to be 5%/Gy, based on the ICRP recommendation to halve the risk of 10%/Gy derived from atomic bomb exposures to high doses and high dose rates because of the low dose and low dose-rate exposure. Thus, given that most Chernobyl related whole body exposures were to doses less than 50 mGy and populations in excess of 1 million participants would be required to reach statistical significance in epidemiological studies of fatal cancer, lifespan studies along the lines of the atomic bomb survivors study were not proposed after 1986. The high incidence of a cancer with a low fatality rate was not foreseen.

Developments in radiobiology and radiation epidemiology have questioned this assessment of low dose risk. Radiobiological effects that cannot be accommodated in proposals based on target theory and microdosimetry have been observed. A detailed analysis of the low dose region of the solid cancer risks of the atomic bomb survivors (see Fig. 1) and other epidemiological studies of low dose and low dose rate exposure indicate that risk could be close to that directly extrapolated from findings at higher doses (i.e., without the twofold reduction) or greater (17). In addition, the atomic bomb survivors and other studies have revealed dose related increases in non-cancer diseases at moderate doses many years after exposure (18-20): the possibility that cancer may not be the only health consequence in the Chernobyl exposed populations clearly should be studied.

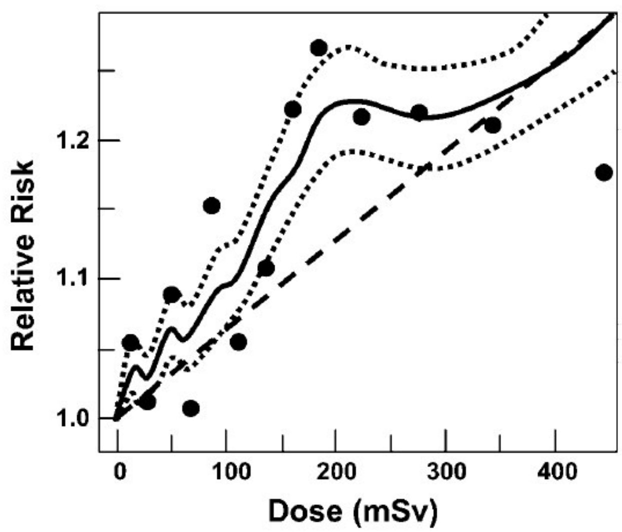

Figure 1. Estimated risks (relative to an unexposed individual) of solid cancer in atomic bomb survivors exposed to low radiation doses. Data points are placed at the mean of each dose category. The solid curve represents a weighted moving average of the points shown (dotted curves:±1 SE), and the dashed straight line is a linear risk estimate computed from all the data in the dose range from 0 to 2,000 mSv. Age-specific cancer rates from 1958 to 1994 are used, averaged over follow-up and gender (Reproduced from Pierce & Preston, 2000 (21)).

In addition, questions about the health of future generations are raised by observations of radiation induced instability in the offspring of irradiated fathers (12). The health consequences of these are unclear at present but the effect is consonant with various animal studies, raising the possibility of an increased cancer burden for future generations.

These issues are addressed in more detail in individual research proposals.

Chernobyl research issues of scientific importance

The unprecedented nature of the Chernobyl accident allows studies that can improve our understanding of the interaction of radiation with living tissue and the consequences that follow. The major areas are described below:

Dose response, including internal doses, for cancer and non-cancer diseases

Current radiation protection policies are based on a linear non-threshold (LNT) model for the effects of low dose radiation, where health risks such as cancer are assumed to be directly proportional to dose. There are considerable uncertainties in assessing low dose risks, including the lack of statistical power of population studies.

Chernobyl research could make a significant contribution to this debate as risk estimates could be determined from studies of large cohorts of liquidators with known doses or from the fallout exposed population. Chernobyl Registries contain information on approximately 600,000 liquidators from Belarus, Russia, and Ukraine, between them contributing over 10 million person-years of observation; cohorts also exist in the Baltic countries. Many of these workers were exposed to less than 100 mGy. In addition, many millions among the general population were exposed to low doses from fallout; assembling a large cohort with known doses from this group would be possible, although complex. The sheer size of these cohorts is likely to provide the necessary power to detect small effects at lower doses than any other cohorts.

Significant advances in knowledge have already been made through a number of studies, especially of thyroid cancer and cataract (4;7). For the latter, the data challenge the current position that there is a threshold dose below which cataract does not occur. For these and other effects the risks are likely to change with latency, and full assessment requires continuing study.

Other types of cancer with a longer latency, such as breast cancer, may now be increasing in incidence (5), and these too need study. Recent findings from atomic bomb studies of non-cancer effects, e.g. cardiovascular diseases (19), at relatively low doses present a particular challenge for current radiation protection systems. Cardiovascular consequences are difficult to study, and they are therefore not currently considered in the radiation protection assessments. Cardiovascular diseases could be addressed in careful epidemiological studies of Chernobyl liquidators with low to moderate dose exposures.

Latency, aetiology, molecular and clinical evolution of thyroid cancer

Although much has been learned about thyroid cancer from studies of the Chernobyl accident, the size of the outbreak, the fact that new cases continue to occur, and the relatively high attributable fraction afford an unprecedented opportunity for answering a number of questions of scientific and health related importance.

These include the risk to those who were adults at exposure, the change in risk with time since exposure, the role of dietary iodine and other environmental factors and the role of inherited factors, such as mutations in DNA repair genes. The morphological subtype, clinical behaviour and oncogenes involved have all changed with increasing latency; the consequences of future changes require continuing study (4). Such a large number of radiation induced cancers provides a unique opportunity to answer questions about the way in which radiation interacts with the genome, giving rise to tumours with differing latencies and their associated features. Tissue banks storing tumour and other tissues and repositories for nucleic acid samples will be of considerable importance. Further exploration of the interaction between the genetic changes and clinical behaviour may be used to determine treatment, and the possibility that germline changes conferring susceptibility to radiation induced carcinogenesis could also lead to a greater likelihood of adverse effects following radiation therapy needs study. The unprecedented number of radiation induced tumours of one type provides a major opportunity to study the long-term evolution of cancer, gaining information of value to human health and science.

Individual sensitivity

One of the key questions in radiation research is whether generalising a single dose response relationship for all radiation induced outcomes is appropriate. A concerted epidemiological approach to address the issue of individual sensitivity, in particular the role of genetic and epigenetic factors as well as age and environmental factors in modifying susceptibility, is needed. Chernobyl would be an invaluable resource in these efforts as it has large populations from which to draw study subjects to conduct integrated epidemiological studies aimed at elucidating the underlying mechanisms.

Problems of preconceptional and in utero exposure

The finding of minisatellite instability in unirradiated children compared to their exposed parents raises important problems. The instability, which must have occurred in a parental germ cell (although not necessarily manifested as a molecular change until after inheritance) is an example of a non-targeted effect. Whether it is associated with any demonstrable health effect is not known: studies in animals suggest that there may be effects, and that the change is transmitted to further generations in a non-Mendelian manner. Further work is obviously important, and epigenetic effects (and possible associated health consequences) could be studied in the unexposed offspring (currently children and grandchildren) of persons exposed after Chernobyl.

A review in 1997 concluded that radiation doses of the order of 10 mGy received by the foetus *in utero* can significantly increase the risk of childhood cancer (22). Results of a thyroid screening study among children exposed *in utero* to I-131 from Chernobyl fallout suggested an increased risk of thyroid carcinoma 20 years after the exposure (23). Some European ecological studies found that *in utero* radiation exposure from Chernobyl fallout increased the risk of infant leukaemia, others did not. The large European Childhood Leukaemia-Lymphoma Study (ECLIS) (24) found no statistically significant trend of excess leukaemia incidence with increasing dose in Europe in the first five years after the accident. The ECLIS study encountered problems in cancer registration and demographic data: this study should be revised and extended to include all malignancies, using more precise data. To date, only one Chernobyl related analytical population study specifically designed to examine the long-term health effects of radiation exposure *in utero,* has been conducted (25). Further studies, with quantitative risk estimates based on individual doses, would provide invaluable information for radiation protection policies.

Key public health questions which can be answered from studies of Chernobyl exposed populations

Clearly it is imperative that the public health consequences of the Chernobyl accident are fully known to provide the knowledge base for decision making in defining public health policies, radiation protection and the management of future accidents. Studies to date have already provided information of considerable value, outlined above, but there are areas where studies have produced conflicting results. A generally accepted assessment of all health consequences for both the liquidators and the general population covering the first 25 years after exposure is lacking.. Comprehensive studies are needed for the lifespan of those exposed, and studies with a negative result are important in defining risks.

Cancer risks

In considering Chernobyl fallout related cancer effects apart from the thyroid cancer there are at present no clearly demonstrated radiation related increases in cancer risk. This should not be interpreted as implying that no increase has occurred or will occur in future in non-thyroid cancers, as many radiation-related cancers are known to have a long latency, often of decades.

The Expert Group recommends that monitoring of cancer rates is a **high priority** to determine whether there has been any increase in leukaemia and other types of malignancy (Fig. 2). In addition, there should be targeted studies of individual tumour types:

- Thyroid tumours (evaluation of clinical, biological and epidemiological changes over time; effects of exposure as an adult, possible age related changes in latency, follow-up of treated children, role of modifying factors);
- Haematological diseases (retrospective assessment of trends in infant and childhood leukaemia, analytical studies of liquidators and environmental exposures);
- Breast cancer;
- Tumours where registry data suggests a possible radiation related increase may require specific study. Surveillance of specific types of cancer where an association has been suggested is needed.

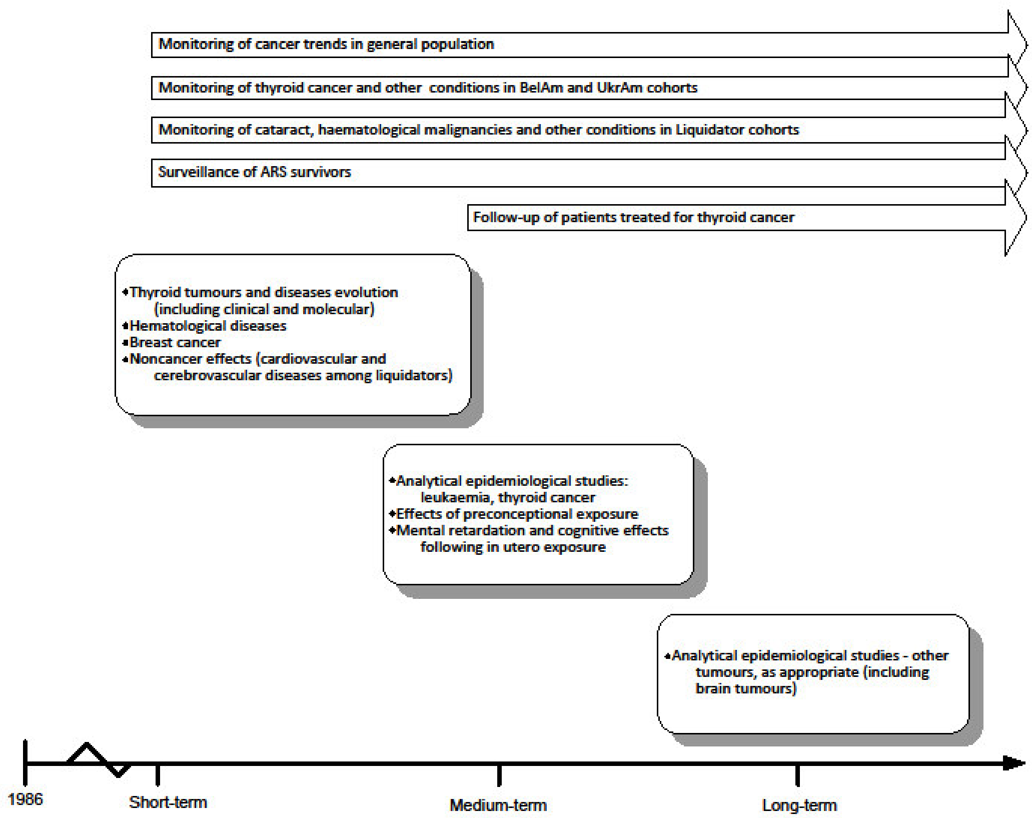

Figure 2. High priority epidemiological projects aimed at answering key public health and research questions by time of implementation (time scale should be interpreted as the urgency of implementation of various projects).

This work must be continued into the foreseeable future to cover the possible development of long latency cancers and to determine the total impact of the accident on cancer incidence. In the longer-term, if increases in specific tumour incidences are detected, screening programmes of selected groups may be considered for individual and public health benefits.

Non-cancer risks

Despite their potential importance these have received little attention to date. Because of the absence of complete high-quality disease registries for non-cancer outcomes, specific studies of appropriate populations are needed.

The Expert Group recommends that monitoring trends of non-cancer diseases risks is of **high priority** (Fig. 2) and that, at the current time, the following issues should be evaluated:

- Cataracts among liquidators;
- Cardiovascular and cerebrovascular diseases among liquidators;
- *In utero* effects including mental retardation and cognitive effects;
- Studies of Chernobyl families will become of importance for public health if studies show that radiation induced transgenerational instability can be associated with adverse health effects in the offspring.

Treatment and follow-up of radiation induced diseases

There are two areas where the consequences of the Chernobyl accident are particularly important for advances in the management of radiation induced diseases. In the immediate phase of the accident, unique experience was acquired on the clinical management of patients with acute radiation syndrome (ARS). The Chernobyl ARS survivors form the world's largest group and the late health consequences need formal evaluation to assess the relevance of the experience gained from their rehabilitation and follow-up to other acute high dose radiation situations. The Expert Group recommends that patients treated for ARS, as well as those treated for radiation effects but not fulfilling the criteria for ARS, should be followed up with **high priority** (Fig. 2).

Large numbers of radiation induced thyroid cancers have been treated after Chernobyl, and the results of the different treatments used will give important information. This is particularly true for the children of very young age treated with high doses of iodine-131; lifetime follow-up is needed to assess the benefits and long-term complications. The results will provide important information for the future management of such cases.

Importance of studies for preparedness for future accidents

The results of the studies mentioned above will be of great importance in the event of another major release of radioactive materials. They will be needed for decisions on radiation protection, countermeasures planning, screening, treatment and follow-up of radiation related diseases. The demonstration that dietary iodine and age at exposure have a major influence on the incidence of radiation induced thyroid cancer is very relevant to the prevention of thyroid cancer after future releases of radioiodines, and it is important to ascertain for how many decades the greatly increased risk for those exposed in childhood is maintained. Other areas where Chernobyl research has already shown results that will affect the precautions needed in the event of future accidents include the risk of cataract at lower doses and potential for the hereditary transmission of genomic instability by exposed fathers.

Implications for radiation protection

Radiation is ubiquitous, and human exposure is increasing, largely through medical use. The standards for radiation protection are mainly based on the atomic bomb survivors studies, supported by smaller studies on those exposed occupationally, and those treated medically. The great majority of these studies assess the risks of external exposure of adults. One of the major components of the release from Chernobyl was iodine-131, which gave rise to internal exposure to radiation; here too, before Chernobyl, studies of the associated risks were almost all carried out in adults. There are four general areas in which continuing studies of Chernobyl effects can contribute to radiation protection standards: the risks of internal as compared to external radiation; the risks of exposure in childhood; the risks of low dose exposure; and studies of large exposed populations to confirm or modify current assumptions.

One of the great advantages of lifespan studies of the atomic bomb survivors has been that the consequences of exposure in terms of lifetime risks can be assessed. The creation of similar lifespan cohorts for those exposed after Chernobyl will allow very valuable additional information for exposure to both internal and external radiation to be obtained. For example, this will allow assessing whether the thyroid cancer risk following childhood exposure is continued throughout life: limited evidence from external radiation studies suggests that it may reduce after several decades. However, it remains possible that it may increase or that more aggressive cancers may develop. A second example is the development of cataract. Chernobyl related studies suggest that there may not be a threshold for this serious consequence of exposure to radiation. If this is confirmed, changes in radiation protection standards may be warranted; lifespan studies including correlation of cataract risk with age at exposure as well as dose will be extremely important. Evidence for or against a risk of cardiovascular disease from low-dose protracted exposures could also be obtained. These are a few of many areas where Chernobyl related findings may lead to changes in radiation protection standards.

If the health consequences of the Chernobyl accident are not fully assessed throughout the lifetime of those exposed, the present wild speculation will continue and future public health decisions will be based on inadequate evidence.

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ARCH membership and method of working

Core group

The Core group was composed of those who conceived the proposal to the Commission. They were responsible for the overall organisation of the study, for writing the documents, in collaboration with members of an Expert group and advisors (see the description below), for modifying them in the light of the comments of the experts and advisors, and then, when priorities had been agreed by the Expert group, making final changes to meet the comments of the external reviewers (see also the description below).

The Core group consisted of the following members:

- Keith Baverstock, radiobiologist, University of Eastern Finland, Kuopio
- Elisabeth Cardis, epidemiologist, CREAL, Barcelona
- Ausrele Kesminiene, epidemiologist, IARC, Lyon
- Dillwyn Williams, pathologist, University of Cambridge.

Expert group and advisors

The Expert group included leading experts with considerable experience in the follow-up of the health consequences of the Chernobyl accident and representing the essential complementary disciplines: epidemiology, radiation biology, medicine (in particular endocrinology), dosimetry, pathology. The names were approved by the EC. They were chosen to cover all health aspects of the consequences of radiation exposure and included representatives of the three most affected countries and the EU. Members:

- Keith Baverstock, University of Eastern Finland (radiobiology and public health)
- Dmitryi Bazyka, Radiation Research Centre, Ukraine (epidemiology)
- Elisabeth Cardis, CREAL, Spain (epidemiology)
- Vadim Chumak, Radiation Research Centre, Ukraine (dosimetry)
- June Crown, UK (public health)
- Yuri Demidchik, Belarusian Medical Academy of Postgraduate Education, Belarus (thyroid treatment)
- Yuri Dubrova, University of Leicester, UK (genetics)
- Victor Ivanov, MRRC, Russia (epidemiology and risk assessment)
- Ausrele Kesminiene, IARC, France (coordination, epidemiology and medicine)

- Semion Polyakov, RSPC MT, Minsk, Belarus (cancer registration and public health management)
- Christoph Reiners, University Wurzburg, Germany (thyroid treatment)
- Margot Tirmarche, IRSN, France (epidemiology)
- Klaus Trott , Gray Cancer institute, UK, (medicine, non-cancer effects)
- Dillwyn Williams, University of Cambridge, UK (pathology and mechanism of cancer)

Scientists with significant experience in radiation research were also included as **advisors** to ensure harmonization with other existing or planned activities around the world:

- André Bouville, NCI, US (dosimetry)
- David Brenner, Columbia University, US (radiobiology)
- Vladimir Drozdovitch, Belarus, currently at NCI, US (dosimetry)
- Ian Fairlie, UK, (environment)
- Bernd Grosche, Federal Office for Radiation Protection, Germany (epidemiology)
- Sisko Salomaa, STUK, Finland (radiobiology)
- Richard Wakeford, University of Manchester, UK (epidemiology)
- Shunichi Yamashita, University of Nagasaki, Japan (thyroid diseases),

as well as the UNSCEAR secretary, Malcolm Crick and Zhanat Carr, WHO, Geneva.
The members of the Expert group and advisors met on three occasions. They reviewed and completed, when appropriate, in their area of expertise, draft position papers and documents prepared by the Core group and agreed on the priorities.

External peer review group

Members of the peer review group are recognised experts in epidemiology, biology (radiobiology) and public health but otherwise not involved in ARCH and not specifically linked to work on Chernobyl. They were therefore able to give an independent assessment of the quality of the SRA, and on the relevance of the proposals to radiation health effects generally. The candidates were nominated during the first meeting of the Expert group and advisors. They were sent the completed Strategic Research Agenda at the end of the project, and returned their comments and suggestions which were acted upon by the Core group. The Core group took into account their comments, suggestions and criticisms in drafting the final version of the Research Agenda.