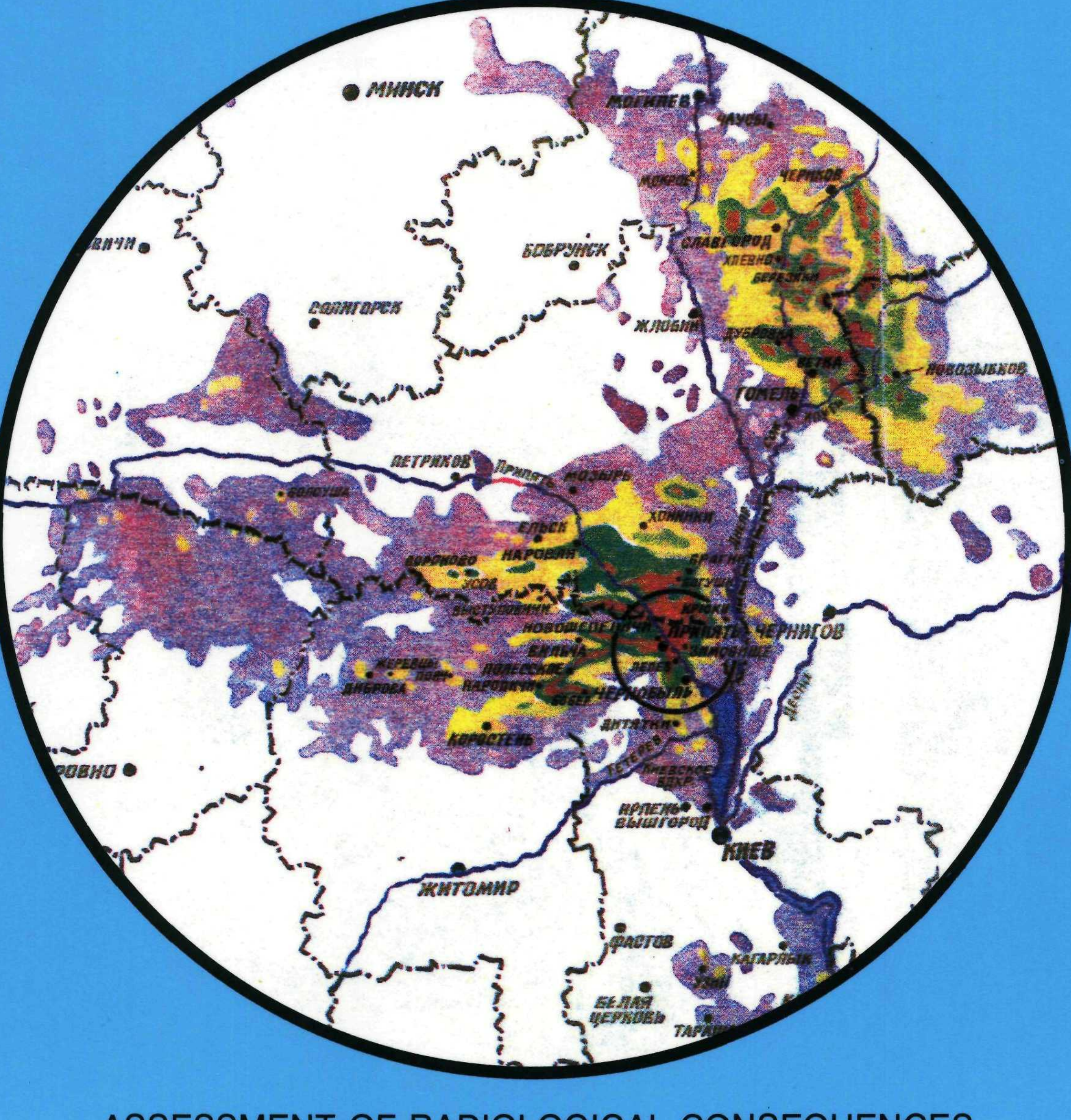
THE INTERNATIONAL CHERNOBYL PROJECT

AN OVERVIEW



ASSESSMENT OF RADIOLOGICAL CONSEQUENCES AND EVALUATION OF PROTECTIVE MEASURES

REPORT BY AN INTERNATIONAL ADVISORY COMMITTEE

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and Evaluation of Protective Measures

Report by an International Advisory Committee

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Acknowledgements

The International Advisory Committee wishes to thank the large number of people who were involved in so many different ways in the International Chernobyl Project — the governments, institutions and organizations who donated the time of their staff and the many individuals who gave of their own time for this important work. Gratitude is expressed to the governments and commercial companies which provided equipment and supplies, without which some major parts of the work could not have been carried out. The complete acknowledgement list is included in the Technical Report.

It is impossible to overestimate the value of the assistance and contribution of the many authorities at the All-Union and Republic levels, and the scientists, experts, technical and administrative staff and members of the public who co-operated with the visiting Project teams. Thanks are also due to the population and the authorities (including physicians, nurses and other staff of hospitals and polyclinics) in the settlements visited.

A considerable debt of gratitude is due to the IAEA Secretariat, who overcame the many difficulties inherent in an effort of such complexity.

Preface
by the Chairman of the International Advisory Committee

It was my privilege to act as Chairman of the International Advisory Committee (IAC), which was composed of prominent experts in different fields. They were called together by the various participating organizations of the United Nations system and the Commission of the European Communities. The IAC approved the work plan for the International Chernobyl Project described in the present Overview and monitored its implementation. The aims of the Project were to examine assessments of the radiological and health situation in areas of the USSR affected by the Chernobyl accident and to evaluate measures to protect the population.

The task assigned to the IAC was a formidable one. There were unavoidable constraints on the time, manpower and funds available for the assignment. The Project was centred on questions of continuing mass relocation of people and sought to provide sound scientific bases for decisions yet to be made.

The Project teams applied their collective expertise and experience to sort facts from misconceptions and radiation effects from effects not related to radiation exposure. They obtained and examined vast quantities of data in their task to understand the present situation and to draw conclusions on the further steps that might be taken to alleviate the consequences of the Chernobyl accident.

The IAC set out to conduct an independent, scientifically authoritative study and to provide a readily understandable report that could assist the authorities in deciding how to proceed. Only time will show the significance of our contribution.

My profound thanks go to all those who contributed to this work: the members of the Committee; the consultants; the task leaders; the team leaders and all the experts who participated; the secretariat of the Project; and the many officials of the USSR, the BSSR, the RSFSR and the UkrSSR who gave their time and efforts to assist the Project.

Itsuzo Shigematsu
Radiation Effects Research Foundation
Hiroshima, Japan

Editorial Note

This Overview presents the conclusions and recommendations of the International Advisory Committee which directed the project on the Radiological Consequences in the USSR from the Chernobyl Accident: Assessment of Health and Environmental Effects and Evaluation of Protective Measures (hereinafter referred to as 'the International Chernobyl Project'). For a more detailed scientific account, the reader is referred to the full Technical Report, in which the various technical chapters have been written by the relevant task leaders of the Project. It is the primary authoritative document of the Project. While the wording of the conclusions and recommendations presented in the Overview has been agreed upon by the members of the Committee, the additional parts of the document were compiled from the Technical Report and provide a summary of the evidence on which the conclusions and recommendations are based.

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Chapter One: The International Chernobyl Project

Introduction

The accident at the Chernobyl power plant occurred on 26 April 1986. A brief chronology of some relevant events up to the inception of the International Chernobyl Project is given overleaf and a more extensive account is presented in the Appendix.

In October 1989, the Government of the USSR formally requested the International Atomic Energy Agency (IAEA) to carry out:

> "... an international experts' assessment of the concept which the USSR has evolved to enable the population to live safely in areas affected by radioactive contamination following the Chernobyl accident, and an evaluation of the effectiveness of the steps taken in these areas to safeguard the health of the population."

The response was a proposal for a multinational team to undertake an assessment of the radiological situation in the three affected Soviet Republics — the Ukrainian Soviet Socialist Republic (UkrSSR), the Byelorussian Soviet Socialist Republic (BSSR) and the Russian Soviet Federated Socialist Republic (RSFSR). The International Chernobyl Project was thus arranged, with the participation of the Commission of the European Communities (CEC), the Food and Agriculture Organization of the United Nations (FAO), the International Labour Office (ILO), the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), the World Health Organization (WHO) and the World Meteorological Organization (WMO). The Project was formalized at a February 1990 meeting in Moscow at the headquarters of the USSR State Committee on the Utilization of Atomic Energy. Some twenty-five representatives of the USSR, the BSSR, the UkrSSR and the IAEA took part in discussions on the goals of the Project and the methods to be used in achieving them.

The Government of the USSR had already benefited from international assistance with this problem. The WHO sent a team of experts in June 1989, as did the League of Red Cross and Red Crescent Societies in early 1990. The final report of the WHO group concluded inter alia that: " ... scientists who are not well versed in radiation effects have attributed various biological and health effects to radiation exposure. These changes cannot be attributed to radiation exposure, especially when the normal incidence is unknown, and are much more likely to be due to psychological factors and stress. Attributing these effects to radiation not only increases the psychological pressure in the population and provokes additional stress related health problems, it also undermines confidence in the competence of the radiation specialist." The Report of the League of Red Cross and Red Crescent Societies indicated inter alia that: "Among the health problems reported it was felt that many of these, though perceived as radiation effects both by the public and by some doctors, were unrelated to radiation exposure. Little recognition appears to have been given to factors such as improved screening of the population and changed patterns of living and of dietary habits. In particular, psychological stress and anxiety, understandable in the current situation, cause physical symptoms and affect health in a variety of ways."

It was clear that the assessment of the Chernobyl accident had already involved extensive efforts and it would not be necessary for the Project to undertake a totally new, comprehensive assessment of the situation. Rather, the task would be to assess the quality and correctness of the existing results. Secondly, to be manageable, the

CHRONOLOGY OF MAJOR EVENTS

26 April 1986	Accident occurs 01:23. Governmental Commission formed
27 April 1986	Evacuation of Pripyat takes place
6 May 1986	End of 10 days of atmospheric release of radioactive material from the core
6 May 1986	Introduction of 'temporary permissible levels' for drinking water and foodstuffs
6 May 1986	Evacuation of the population within the prohibited zone completed
31 May 1986	Revision of 'temporary permissible levels'
May 1986	'Temporary dose limits' for the population set at 100 mSv (internal and external) annual total dose
July 1986	First summarized contamination map (not published until 1989)
November 1986	Completion of the 'sarcophagus' construction
— 1987 —	'Temporary dose limits' for the population reduced to 30 mSv annual total dose (subsequently lowered to 25 mSv for 1988)
April 1987	Completion of the work begun in May 1986 for protecting the water system
December 1987	Revision of the 'temporary permissible levels' established 31 May 1986
— 1988 —	'Temporary dose limits' for the population reduced to 25 mSv annual total dose
September 1988	Council of Ministers of USSR adopts the 350 mSv lifetime dose for relocation to be implemented as of 1 January 1990
March 1989	Contamination maps officially published in the three Republics
April 1989	BSSR Academy of Sciences registers disagreement with the 350 mSv lifetime dose concept and makes new proposals
October 1989	USSR requests the IAEA to organize an international assessment of the consequences of the accident and the protective measures taken

international assessment would have to focus on the key issues of concern to the population and policy makers, namely: the true extent of the contamination; the past, current and future radiation exposure of the population; the actual and potential health effects; and the adequacy of measures being taken to protect the public.

The work of recommending an approach for examining these issues was given to a group of ten scientists, who, accompanied by two members of the USSR Supreme Soviet, travelled on a fact finding mission through the affected Republics over the period 25–30 March 1990. Their visit enabled them to learn first hand about the requirements of the Project. The group met with officials in Moscow and the Republic capitals and with representatives of scientific organizations, hospitals, clinics and agricultural centres in the affected areas and in the cities of Kiev, Gomel and Moscow.

But it was in the encounters with the people of the USSR, from the first meeting at the airport in Kiev to the last question at a packed town hall, that the dimensions of the task became clear. Plans for the Project were presented to residents of seven settlements in the three Republics, who were invited to share their feelings and ask questions. The international scientists found themselves responding to very human concerns. Anxiety about children's health and worries over the adequacy of the Government's proposed measures for limiting the radiation exposures over their lifetime dominated the discussions. There was an atmosphere of mistrust directed at the authorities and also at many in the scientific and medical communities.

Following the visit, an International Advisory Committee of scientists from ten countries and seven international organizations was established to direct the Project and be responsible for its findings. Members were called together by international organizations participating in the Project from well known institutes and universities to represent a spectrum of disciplines, from the radiation specialist to the medical practitioner and the psychologist. The twenty-one member Committee met in Kiev and Minsk from 23 to 27 April 1990 under the chairmanship of Dr. Itsuzo Shigematsu, Director of the Radiation Effects Research Foundation in Hiroshima, Japan.

The Committee agreed upon a detailed work plan. This would be constrained by a compelling need to complete the project in one year and by the limitation on the resources available. The Committee would need to rely on the availability of specialized professionals who would volunteer their time.

Goals and Scope

The International Chernobyl Project was not intended to have the rigour and comprehensiveness of an elaborate long term research study. Nor was it even remotely intended to duplicate the voluminous existing assessments of the environmental contamination, the radiation exposures of the population and possible health effects due to exposures resulting from the accident. The intention was to have a multidisciplinary group of international experts critically examine the extensive information, address the key issues and put together an understandable picture of the current situation.

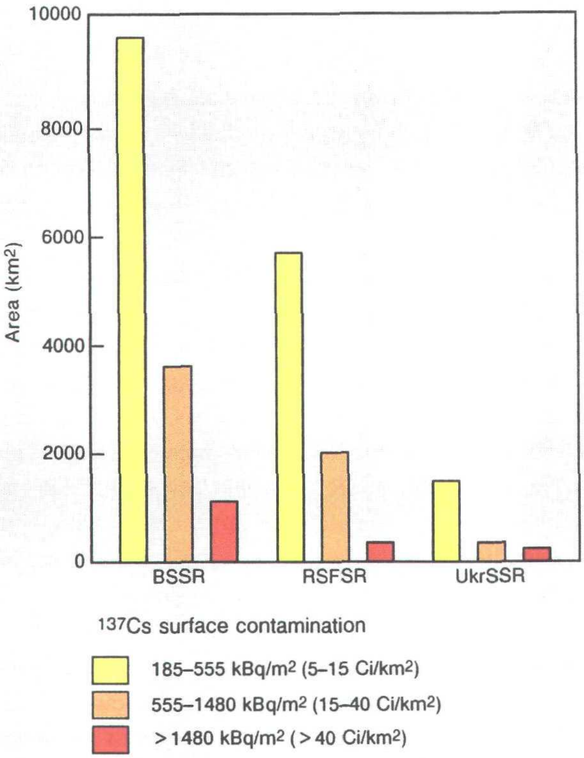
The goals of the Project, in short, were to examine assessments of the radiological and health situation in areas of the USSR affected by the Chernobyl accident and to evaluate measures to protect the population.

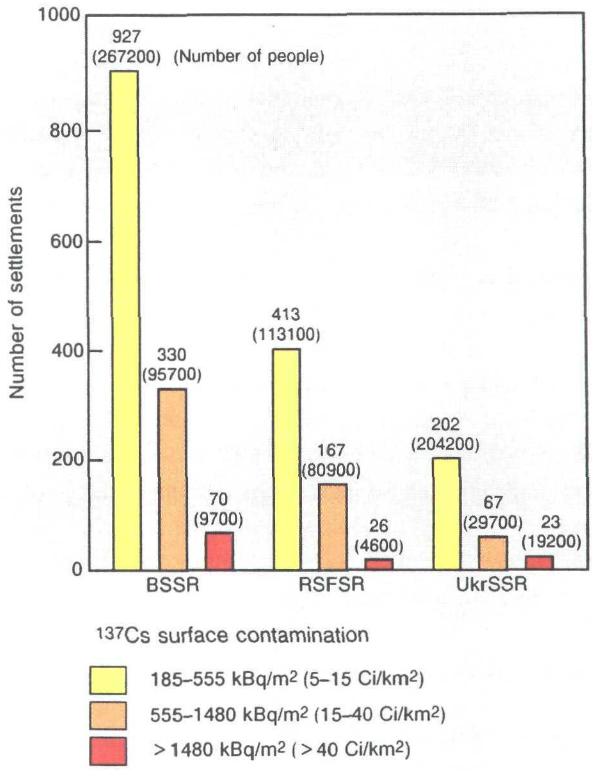
Thirteen districts in the USSR have been officially identified as having a ground level ^{137}Cs contamination in excess of 1 Ci/km^2 (37 kBq/m^2)[1]. Approximately 25 000 km^2 are defined as affected areas with ground concentration levels of ^{137}Cs in excess of 5 Ci/km^2 (185 kBq/m^2). Of this total, approximately 14 600 km^2 are located in the BSSR, 8100 km^2 in the RSFSR and 2100 km^2 in the UkrSSR. The Project deals with these affected areas. It was not in its terms of reference to examine the prohibited region (approximately 30 km in radius) around the damaged reactor itself, except to describe the measures taken to contain the accident in the early post-accident phase. It deals exclusively with the radiological consequences for the people living in the affected areas at the time the assessment began in 1990. From official USSR reports, this population is approximately 825 000, of which 45 per cent live in the BSSR, 24 per cent in the RSFSR and 31 per cent in the UkrSSR.

Work Plan

The work plan adopted called for examining the validity of the official methodologies and findings, and

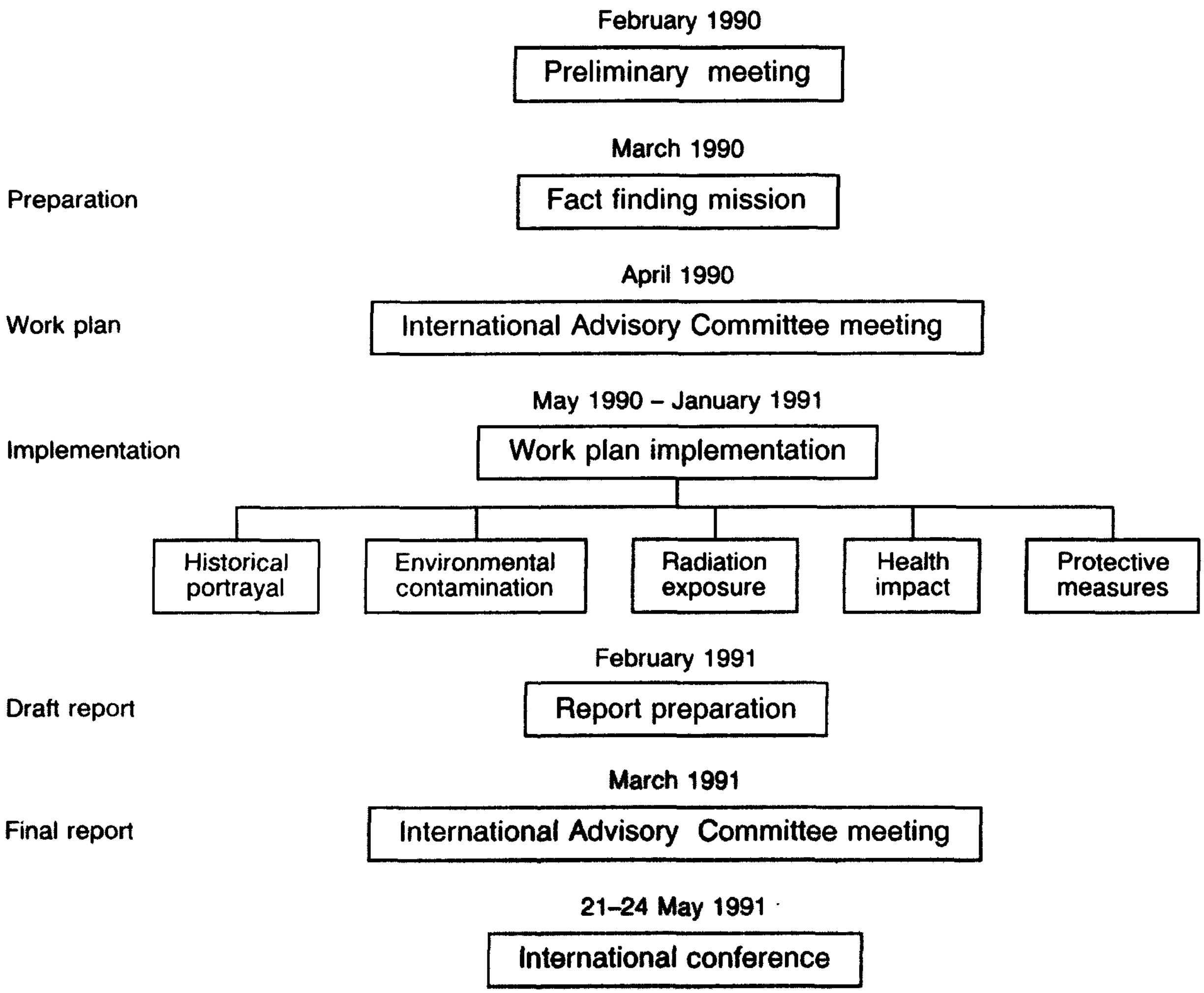
[1] Units of the Système international d'unités (SI) are generally used worldwide. However, in the USSR earlier units are still used and the original data were usually presented in these units. The data in this Overview are therefore expressed in both units.





Geographical framework. *The international assessment focused on the approximately 25 000 km^2 in the BSSR, the RSFSR and the UkrSSR officially reported to have a caesium surface contamination level in excess of 185 kBq/m^2 (5 Ci/km^2) and particularly on those areas with a level greater than 1480 kBq/m^2 (40 Ci/km^2). The assessment excluded the prohibited zone (30 km in radius) around the Chernobyl reactor. [Doc. A/45/342 E/1990/102, United Nations Economic and Social Council, Geneva, 9 July 1990.]*

Demographic framework. *The international assessment addressed the radiological consequences for the approximately 825 000 people living in 2225 settlements in the BSSR, the RSFSR and the UkrSSR. It did not include those people who had lived in contaminated areas but had since moved from those areas. Nor did the Project address possible consequences for the so-called 'liquidators', i.e. the recovery workers occupationally exposed at the Chernobyl plant site. [Doc. A/45/342 E/1990/102, United Nations Economic and Social Council, Geneva, 9 July 1990.]*



The International Chernobyl Project. *The Project was organized in response to a USSR Government request for an international assessment of the radiological consequences of the Chernobyl accident. The multinational effort was directed by the International Advisory Committee and included the participation of the CEC, FAO, IAEA, ILO, UNSCEAR, WHO and WMO. Five tasks defined the Project implementation: historical portrayal of the events leading to the current radiological situation, the evaluation of the environmental contamination, the evaluation of the radiation exposure of the population, the assessment of the health impact from radiation exposures and the evaluation of the protective measures.*

independently verifying them through field samples, laboratory analyses and internationally recognized calculational techniques. A portrayal of the major historical events would also be prepared to provide the necessary background to more fully understand the complexity of the situation and the interrelated nature of the Project's goals.

The work covered five areas or 'tasks':

Task 1: Compilation of a historical portrayal of events leading to the current radiological situation (see Appendix)
Task 2: Evaluation of the environmental contamination assessments
Task 3: Evaluation of the radiation exposure assessments
Task 4: Assessment of clinical health effects from radiation exposure and evaluation of the general health situation
Task 5: Evaluation of protective measures

The Project selected, in co-operation with local authorities, a number of settlements in the contaminated areas of concern in order to perform the necessary surveys. Some of the settlements were located in areas of relatively high soil surface contamination while others were located in areas of relatively low soil surface contamination but with the potential for high radiation doses to people. In this Overview, these settlements are called 'surveyed contaminated settlements'.

Settlements were also selected outside the contaminated areas of concern to serve as references for comparative purposes. These settlements are called 'surveyed control settlements'.

The surveyed contaminated settlements were:

Bragin	Novozybkov
Daleta	Novye Babovichi
Gden	Ovruch
Gomel	Polesskoe
Khojniki	Rakitnoe
Komrin	Savenki
Korchevka	Savichi
Korma	Slovechno
Malozhin	Staroe Vasil'kovo
Michul'nya	Starye Babovichi
Mikulichi	Svyatsk
Milcha	Veprin
Narodichi	Zhatka
Novoe Mesto	Zlynka

The surveyed control settlements were:

Chemer	Surazh
Khodichi	Trokovichi
Kirovsk	Unecha
Krasilovka	

Not all the settlements were used in all the tasks of the Project.

A parallel consideration was the desire of the affected population to receive practical information about how they could deal with the radiological situation. Project experts concluded that there was a poor understanding in the affected areas of the scientific principles underlying radiation and its effects (as is generally the case throughout the world) and that this was at the root of many of the medical and social problems observed. Therefore, in addition to the main tasks of the Project, several information exchange activities were carried out in order to enhance the level of understanding among the local scientific community of the problems involved.

Participation

The Project was carried out on a completely voluntary basis by a closely co-operating team of some 200 experts associated with research institutes, universities and other organizations in 25 countries and 7 multi-

INFORMATION EXCHANGE ACTIVITIES

MEDICAL SEMINARS

Three-day seminars were held in July 1990 in a number of villages in each of the three Republics to broaden the knowledge of the general practitioners and health administrators. More than 1200 local experts joined the visiting team of four international specialists in discussing the results of long term studies on radiation induced and related illnesses, the ways such illnesses can be diagnosed and treated and the methods that are used to study cancer and other diseases in populations exposed to radiation.

AGRICULTURAL ACTIVITIES

A fact finding mission to the USSR in August 1990 identified the concerns of farmers and farm workers about living and working in a contaminated agricultural environment. At a one-week workshop in Norway in September 1990, USSR agricultural scientists and ministry officials from the three Republics learned about Norwegian techniques for reducing caesium contamination in milk and meat derived from grazing animals and a series of trials using so-called caesium binders were started. During October and November, a series of one-day seminars were held in villages in the three affected Republics, with Project experts discussing with some 1300 collective farmers, farm workers, veterinarians and others from the local agricultural community how to use these practical methods and other techniques for soil management in contaminated environments.

RADIOECOLOGY SEMINAR

To help local experts better understand the assessment of human radiation exposures following environmental releases of radionuclides, a five-day seminar was held in Kiev in January 1991. More than 200 specialists in radiobiology, radioecology, environmental science and public health from the three affected Republics took part in discussions on such topics as environmental monitoring, the behaviour of radionuclides in the biosphere and the relevance of these nuclides for people.

national organizations. The time devoted to the Project was volunteered by governments, institutes, companies or the experts themselves. Nearly 50 missions to the USSR were completed between March 1990 and January 1991. The IAEA Laboratory at Seibersdorf along with 13 laboratories in six countries participating on a voluntary basis were involved in the collection and analysis of samples. The Laboratory carried out an intercomparison exercise with participating laboratories from the USSR. Governmental authorities and commercial companies in five countries donated equipment and supplies, radiation monitors and computing time to back up the Project work.

The Project received the full support of the USSR Government and the Governments of the BSSR, the RSFSR and the UkrSSR. Assistance took various forms, including the participation of local scientists in intercomparison exercises, extensive discussions with Project scientists, and assistance in the collection and preparation of field samples and in carrying out medical examinations of the population in the affected areas. Most of the logistic support for the Project was provided by the USSR Ministry of Atomic Power and Industry. There were open and frank conversations with authorities, scientists and especially local citizens that greatly helped the international experts' understanding of the situation.

Constraints and Limitations

The conclusions and recommendations of the International Chernobyl Project were approved by the International Advisory Committee (IAC) at its meeting in Vienna from 18 to 22 March 1991 and they are based upon the radiological and health assessments carried out by the Project. The technical details of these assessments are to be found in the extensive Technical Report, to which reference should be made for further information.

The conclusions and recommendations are subject to the constraints and limitations of the Project design. These constraints and limitations should be recognized so that the conclusions and recommendations are not interpreted to be more or less than is warranted by the Project. Ideally, the Project teams would have had sufficient time and resources to examine exhaustively and verify independently all the information available to them as well as to carry out more extensive independent analyses. Such comprehensive efforts were not feasible nor were they altogether warranted. More limited objectives were necessary and were adopted for a number of reasons: the time available to complete the Project was limited; the data provided to the Project teams were not always adequate; the evaluation of the radiological situation immediately after the accident could no longer be independently assessed because of the time that had elapsed and the consequent decay of short lived radio-isotopes; the number of available independent experts as well as their time were limited; the thousands of square kilometres that were contaminated could not be thoroughly monitored or systematically surveyed for 'hot spots' of contamination; and the hundreds of thousands of people living in these areas could not be individually examined. Finally, the Project survey was concerned principally with human problems and relevant environmental considerations such as agricultural contamination; consequences of the accident for other species were not specifically considered.

Efforts were therefore directed to the assessment of data, techniques and methodologies employed to estimate contamination levels, doses[2] and health effects, and to the evaluation of radiological protection policies. Sufficient data were obtained independently to enable the Project teams to formulate independent judgements.

In order to assist the authorities of the USSR, the BSSR, the RSFSR and the UkrSSR, major efforts were devoted to the urgent need to provide guidance with respect to radiological protection measures (including the 'safe living concept') and the associated radiological protection practices and policies. The radiological considerations influencing a policy such as relocation (for example, the radiation doses and risks averted by relocating populations) had to be evaluated within the context of the resulting psychological, social and economic factors.

An assessment was made of the health of persons who had been residing in settlements in the contaminated areas of concern since the time of the accident. This was done by examining the population for potential health effects due directly to radiation as well as health effects that may have occurred as a result of factors related to the accident but not due to radiation exposure. Since there were few baseline data for these populations from the time before the accident, it was necessary to compare results for these people with those for other people living in the region but outside the contaminated areas of concern.

As the Project was directed at those currently living in the contaminated areas, the radiological

[2] The word 'dose', unless otherwise specified, is generally used to mean 'effective dose', i.e. the total absorbed dose appropriately weighted for the harmfulness of the radiation type and the susceptibility to harm of human tissues.

health effects to the more than 100 000 people evacuated from the prohibited zone around the Chernobyl site were considered only for those currently living in the areas under review. Nor did the Project address health effects for the large number of emergency personnel (the so-called 'liquidators') who were brought into the region temporarily for accident management and recovery work. The health of this occupationally exposed population is reportedly being monitored at medical centres throughout the USSR.

Some issues received comparatively little attention, owing primarily to the unavailability of necessary and sufficient data. For example, it was not possible to corroborate the early contamination of land and the exposures of the public due to iodine isotopes. Nor were the early remedial protective actions undertaken (e.g. thyroid blocking by iodine prophylaxis and evacuation) subject to thorough evaluation.

Despite the limitations of time and financial and human resources, the International Advisory Committee is of the opinion that the Project represents a much needed international humanitarian and scientific response to the needs of the authorities and the people of the USSR who were affected by the Chernobyl accident.

The International Advisory Committee acknowledges the many problems in a study of such breadth. Nonetheless, the work has involved leading and eminent international scientific investigators and medical specialists who endorse its adequacy and its results. It is a significant step in the evaluation of the consequences of the accident.

Chapter Two: Environmental Contamination

The Problem

The Chernobyl accident involved the largest short term release from a single source of radioactive materials to the atmosphere ever recorded. Of the materials released from the reactor core, four elements have dominated the short term and long term radiological situation in the affected areas of the USSR: iodine (primarily ^{131}I), caesium (^{134}Cs, ^{137}Cs), strontium (primarily ^{90}Sr) and plutonium (^{239}Pu, ^{240}Pu). In addition, highly radioactive fuel fragments (hot particles) were released.

Aerial radiation measurements and environmental sampling begun shortly after the accident showed that the highest level of environmental contamination was in the area around the reactor that would eventually become the prohibited zone. Elsewhere in the Soviet Union, changing wind conditions and sporadic rainfall over the ten-day release phase resulted in a very uneven pattern of radioactive fallout within areas of the BSSR, the RSFSR and the UkrSSR.

Heavy rainfall combined with local conditions to create pockets ('hot spots') of exceptionally high surface radioactivity levels resulting in external dose rates that were as much as five thousand times the dose rate due to the natural background. Once releases had been halted, changes in contamination patterns resulted from radioactive decay (primarily of ^{131}I, which decays almost totally within three months) and normal weathering processes which caused the migration of contamination into the soil and the dispersion of soil particles through the runoff of surface waters.

Information from continuing aerial surveys and environmental sampling has been used to derive official surface contamination maps which display the ranges of surface concentration of caesium, strontium and plutonium. Officially published in 1989, the maps have stirred controversy among scientists and residents. About 25 000 km^2 and 2225 settlements in the three Republics are officially defined as having a ^{137}Cs surface contamination in excess of 185 kBq/m^2 (5 Ci/km^2). For the residents there were crucial questions:

- Did the official maps describe the actual surface contamination?
- Were the water resources contaminated?
- Could locally produced milk and food be safely consumed?

Objectives and Approach

It was clear from the outset that this international assessment could not expect to duplicate the four-year efforts of local experts to assess the environmental contamination of such a vast land mass. Project experts sought to examine the official assessments through a three part approach.

Firstly, they reviewed official data and the practices used for data collection and reporting. The official data were presented in the form of surface contamination maps for ^{137}Cs, ^{90}Sr and ^{239}Pu and tables for nearly 500 settlements in the three Republics containing surface contamination values for ^{137}Cs and ^{90}Sr, along with contamination values for environmental samples and food. Local data from regional and Republic institutes were considered.

Secondly, the Project teams visited twenty governmental institutes and laboratories to review their practices and facilities for sampling and analysing environmental materials and food. Reportedly, these

***Official maps.** Maps showing isopleths of surface contamination for caesium, strontium and plutonium were made available to the Project and used for reference purposes. Officially published in 1989 by the USSR State Committee on Hydrometeorology and Environmental Monitoring, Moscow, the maps are reportedly derived from aerial radiation surveys and soil sampling in settlements in known and suspected areas of contamination. These maps can be found in a separate cover.*

particular institutes contribute substantially to the official assessment process. An intercomparison exercise using reference materials containing known quantities of radioactive substances was carried out to evaluate the analytical capabilities of those laboratories which were providing the bulk of the information in the three Republics.

Finally, the Project teams used independent methods and equipment for surveying the radioactivity on the ground, and in the soil, sediments, air, water, vegetation, milk and food. Given the large number of settlements affected and the limited resources available to the Project, only grab sampling and spot measurements were undertaken. Of the surveyed contaminated settlements, the majority are located in the areas with ^{137}Cs surface contamination levels above 555 kBq/m^2 (15 Ci/km^2), while a few have lower contaminations of between 37 kBq/m^2 (1 Ci/km^2) and 185 kBq/m^2 (5 Ci/km^2). In addition, measurements were made in six control settlements defined as areas with contamination below 37 kBq/m^2 (1 Ci/km^2) to verify that they could serve as control settlements for the Project medical teams. The environmental and food samples collected were analysed for radioactivity at laboratories in six countries.

Work in Detail

REVIEWING OFFICIAL DATA AND PRACTICES

A key element of the study was a review of the official methodology for deriving the surface contamination maps. As formalized documentation was not readily available, the team relied on direct discussions with local experts.

The contamination maps are reportedly based on data from aerial gamma radiation monitoring surveys and the analyses of soil samples collected at locations known or suspected to be affected by radioactive fallout. The aerial surveys which were started immediately after the accident are presently carried out twice yearly. There is a central environmental database in Obninsk and databases in each of the Republics. While information is exchanged among the institutes at the regional and Republic levels, the results of radiation measurements obtained at the All-Union level are not normally transferred to the Republic authorities.

The review of official practices and discussions with local experts indicated a well developed infrastructure for assessing radioactivity in environmental materials and food. Institutes with experienced staff range in size from small laboratories with only regulatory control functions to major research bodies. No detailed information was provided on the relative contribution of each institute to the environmental assessment process or on quality assurance programmes for ensuring the quality of the analyses and the reliability of the results.

Surface and, to a lesser extent, groundwater resources are extensively sampled. Rivers and reservoirs in the affected areas are sampled and a specially equipped research ship regularly monitors contamination along the Dnepr River. The Project team noted problems of caesium and strontium cross-contamination in local laboratory preparations and analyses of water and sediment samples which could cause an overestimation of the contamination.

The levels of contamination of milk and meat are monitored. Milk is screened for caesium at dairies and collective farms before processing. Animals selected for slaughter are checked and meat is checked at processing plants and at random at food shops before sale. As information on the calibration of the measuring instruments was not available, the Project teams were unable to evaluate the accuracy of the official measurements.

VALIDATING OFFICIAL RESULTS

An intercomparison exercise organized by the IAEA Laboratory at Seibersdorf provided a yardstick for judging the validity of official data. The 13 institutes that took part are reported to be the most heavily engaged in sampling and laboratory analyses of environmental materials and foods. The institutes analysed 'blind' samples of (radionuclides measured): soil (^{90}Sr, ^{239}Pu, ^{137}Cs, ^{226}Ra); milk powder (^{90}Sr, ^{134}Cs, ^{137}Cs, ^{40}K); simulated air filters (^{90}Sr, ^{137}Cs, ^{60}Co, ^{133}Ba, ^{210}Pb); and vegetation (^{90}Sr, ^{134}Cs, ^{137}Cs, ^{40}K) and reported the results together with the associated numerical uncertainties. The IAEA Laboratory compared their results with the recommended (i.e. 'reference') values.

The reported results for ^{137}Cs in soil agreed well with the recommended values. On the other hand, results for strontium and plutonium in soil showed a tendency for overestimation (by as much as a factor of four). A similar tendency for overestimation was noted for strontium in milk (by as much as a factor of nine) and for caesium in milk (by as much as a factor of three). While results for strontium in vegetation appear generally reliable, there was an observed slight tendency to underestimate caesium. In simulated air filters the results for caesium were in agreement with recommended values while the results for strontium deviated by 30–50 per cent.

INDEPENDENT PROJECT SURVEYS

Independent Project surveys were conducted in selected settlements over a six month period in mid-1990, using internationally accepted methods and equipment. These included external gamma dose rate measurements in indoor and outdoor locations as well as soil, water, air and food sampling. The results were used to assess the official maps of surface contamination by caesium, strontium and plutonium and to enhance understanding of the environmental contamination in the affected areas.

Dose Rate Measurements

Project dose rate surveys in Bragin, Novozybkov, Polesskoe and Daleta were used to examine the official assessments of the range of average values of ^{137}Cs surface contamination in these settlements. Over 2000 measurements were made of the gamma dose rate, which were converted and compared with the official surface ^{137}Cs contamination values.

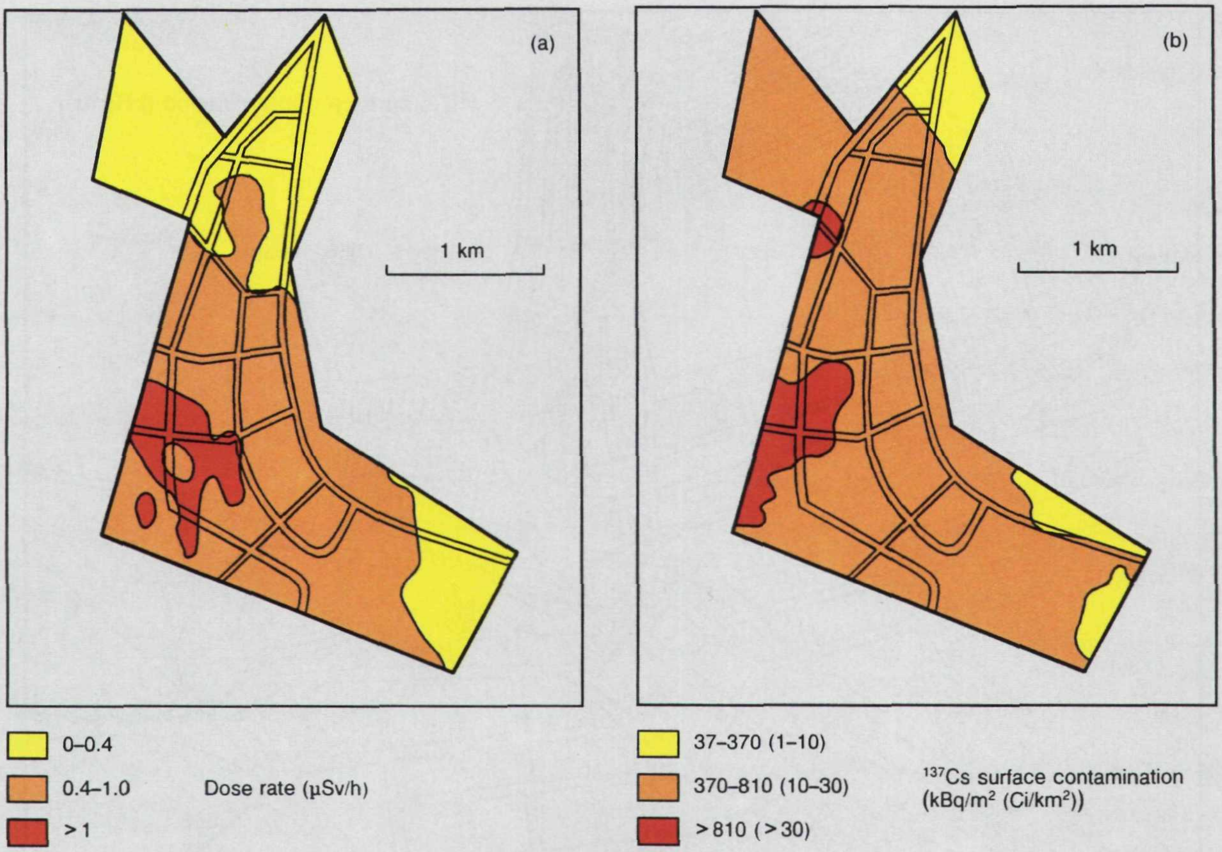
Sampling Programme

Soil

Project soil core samples in Novozybkov, Bragin, Polesskoe and Daleta were also used to determine the radionuclide concentrations at different depths and to examine the official assessments of the range of average values of ^{137}Cs surface contamination in these settlements. A limited number of selected soil samples from Bragin, Daleta and Polesskoe were independently analysed for plutonium (^{239}Pu and ^{240}Pu) and strontium (^{90}Sr) surface activity in the topsoil.

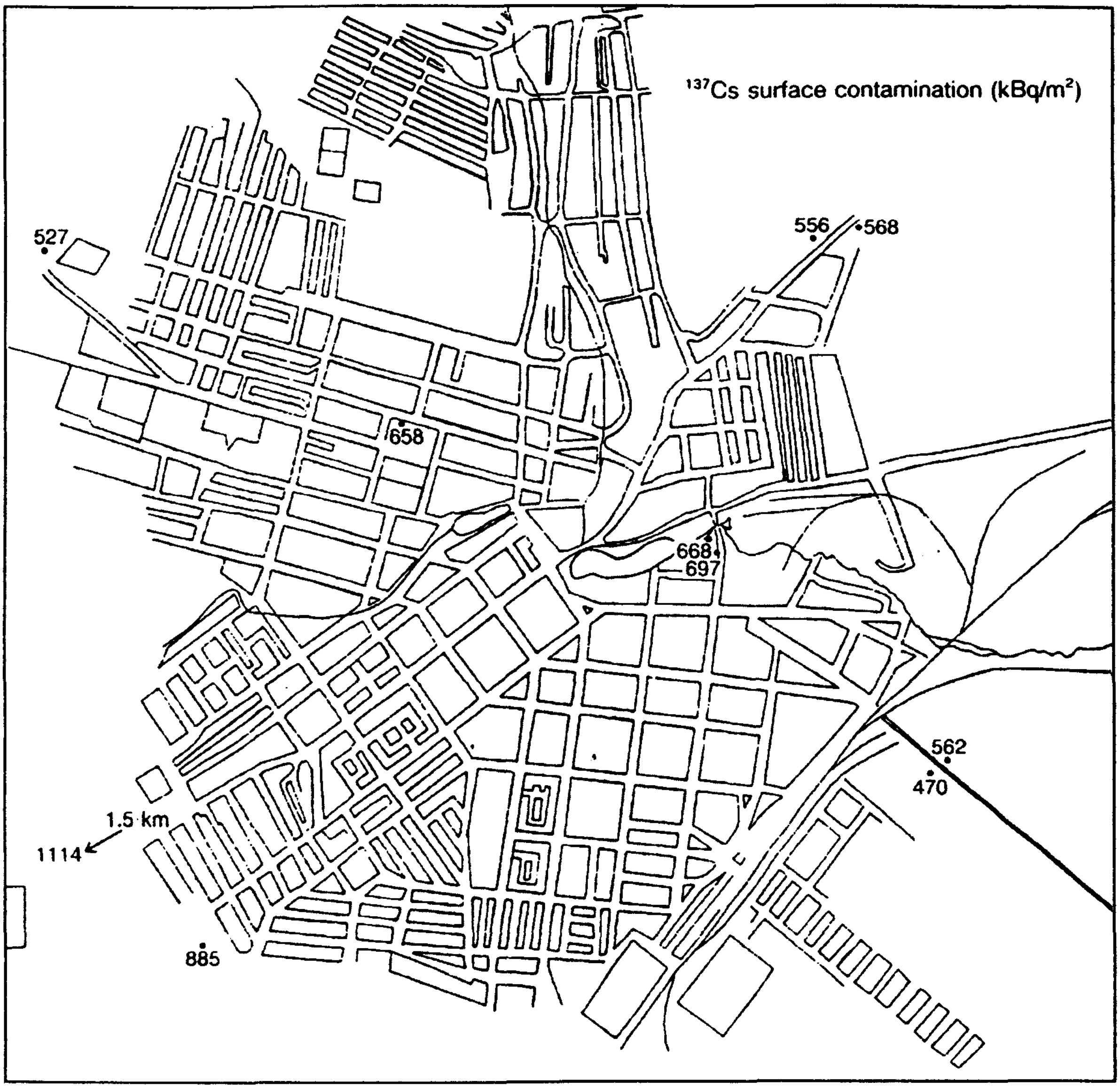
Water Resources

Water samples were taken in 16 settlements in the Bragin, Novozybkov and Ovruch regions to determine

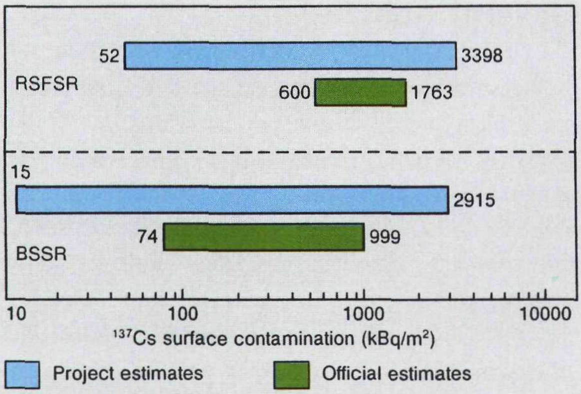


Correlation of Project measurements of dose rate with official values of caesium surface contamination for the settlement of Bragin, BSSR. *Project surveys using independent methods and equipment provided general corroboration of the levels of surface contamination due to caesium given in official maps. As illustrated here for the settlement of Bragin, Project measurements of gamma dose rates in air (a) correlated with the caesium contamination values for that settlement as officially reported by the Byelorussian Department of the All-Union Institute for Agricultural Radiology, Gomel, BSSR (b). Both data sets indicated a variable pattern of surface contamination, with the highest activity concentration recorded in undisturbed locations and the lowest on hard surfaces that presumably have weathered or have been decontaminated.*

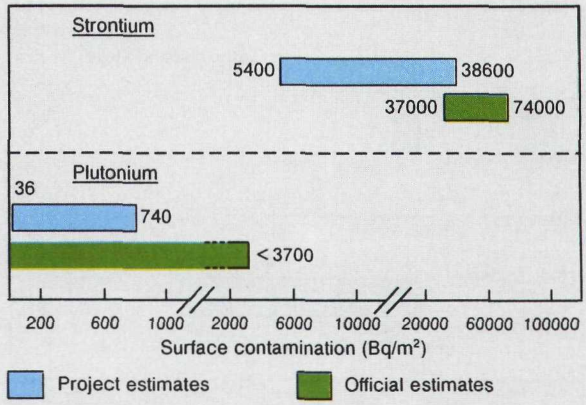
whether deposited radionuclides had contaminated drinking water. The sites included hand dug wells, public water supplies, ponds, lakes and rivers. In addition, sediment samples were taken from lakes, ponds, rivers and reservoirs to assess caesium penetration and to determine the hazards for aquatic systems. The water samples had caesium concentrations usually below the limit detectable by the instruments used. However, sediment samples from areas with relatively high ground contamination show elevated levels in the top layers, representing a potential source of future contamination of biota in these areas.



Project measurements of caesium soil contamination in Novozybkov, RSFSR. *Project efforts to confirm the official values for caesium surface contamination included surveying the radioactivity in the topsoil in selected settlements. As illustrated here for the settlement of Novozybkov, independent sampling of topsoil contamination indicated caesium values ranging from 470 to 1114 kBq/m^2 (12.7 to 30.1 Ci/km^2). These data are in reasonable agreement with the range of average values of 555 to 1480 kBq/m^2 (15 to 40 Ci/km^2) officially reported for that settlement by the USSR State Committee on Hydrometeorology and Environmental Monitoring, Moscow.*



Comparison of Project measurements of caesium soil contamination with official values of caesium surface contamination for settlements of the BSSR and the RSFSR. *Limited Project sampling of caesium contamination in topsoils in five settlements of the BSSR and four settlements of the RSFSR indicated values that were consistent with the range of the official values based on comprehensive surveys carried out since the accident and reported for these settlements by the USSR State Committee on Hydrometeorology and Environmental Monitoring, Moscow.*



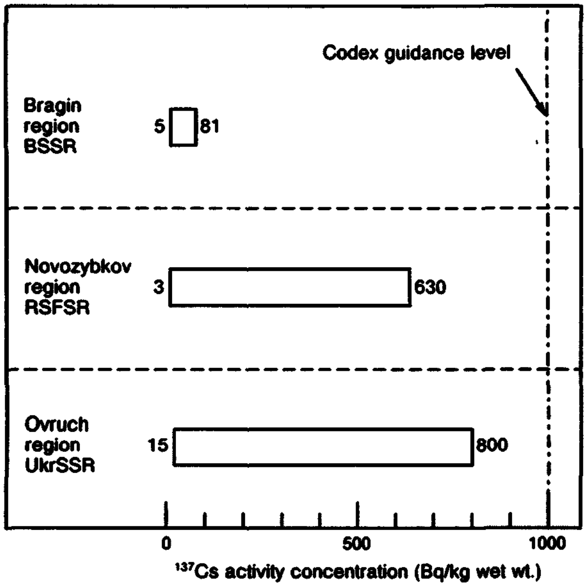
Comparison of Project measurements of strontium and plutonium soil contamination with official values for surface contamination in the Bragin region, BSSR. *The Project concluded that analytical results for a limited set of soil samples corresponded to the reported estimates for plutonium but were lower than those for strontium. As illustrated here for settlements in the Bragin region, the measurements of strontium contamination suggest the potential for overestimation in the official values reported by the USSR State Committee on Hydrometeorology and Environmental Monitoring, Moscow.*

Air

Wind, ploughing and other activities can cause deposited fallout to be resuspended into the air, where the radioactive dust could be inhaled. Air samples were taken in 12 settlements to determine the concentration of resuspended particles. Sampling sites were mainly outdoor locations, such as playgrounds and agricultural areas. Although the measurements indicate low gamma and alpha outdoor air concentrations, heavy rainfall during the period of the investigations and the seasonal coverage of soils with vegetation could have limited the resuspension and contributed to the low readings.

Food and Milk

Food samples representative of the total diet for a single day were collected from residents of settlements in the Bragin, Novozybkov and Ovruch regions. The radioactive contamination of food collected from the commercial sector in the surveyed settlements was generally found to be below guidance values for international trade. However, in a few samples the levels were considerably higher than these values; this may have been a result of lack of compliance with official recommendations regarding the consumption of locally produced or collected food. Results for ^{137}Cs levels in milk samples from settlements in the Bragin, Novozybkov and Ovruch regions showed a similar pattern.



Project measurements of caesium concentration in total diet samples from settlements in the Bragin region, BSSR, the Novozybkov region, RSFSR and the Ovruch region, UkrSSR. *Project analyses of a limited number of total diet samples (e.g. bread, potatoes, vegetables) collected from residents of eleven settlements indicated a relatively large variation in the measured levels of caesium contamination. As illustrated here, the measured values for all eleven settlements in the three regions were below those recommended by the responsible authorities and also below the guidance level for radionuclide contamination with ^{137}Cs (1000 Bq/kg) established by the Codex Alimentarius Commission (1989) for food moving in international trade. For two settlements in the Ovruch region, which officially have a low level of caesium surface contamination, a few samples of locally produced food showed elevated contamination levels. This suggests a high transfer factor between soil contamination and food contamination in those areas surrounding the settlements.*

General Conclusions

Measurements and assessments carried out under the Project provided general corroboration of the levels of surface contamination for caesium as reported in the official maps that were made available to the Project. Analytical results from a limited set of soil samples obtained by the Project teams corresponded to the surface contamination estimates for plutonium but were lower than those for strontium.

The concentrations of radionuclides measured in drinking water and, in most cases, in food from the areas investigated were significantly below guideline levels for radionuclide contamination of food moving in international trade and in many cases were below the limit of detection.

Detailed Conclusions

CAPABILITIES OF SOVIET LABORATORIES

The analytical capabilities of Soviet laboratories appeared to be adequate. There is an extensive infrastructure for the analysis of environmental and food samples. The range of performance of the Soviet laboratories that participated in the intercomparison exercise was broad, but similar to that found in previous international comparison exercises. The few problems identified, including the tendency to overestimate strontium, did not significantly affect the use of data for conservative dose assessment purposes.

The field studies which were assessed, even though they excluded 'hot spots', appeared to give adequate results for the average values characterizing surface deposition in a region. In accordance with the methodology that reportedly had been used, 'hot spots' that had been identified were systematically excluded in the reported estimation of average surface deposition for a given region and were not listed in the detailed data provided to the Project teams.

The extensive surface water sampling programmes are adequate. Certain problems during sampling and/or analytical procedures could lead to possible overestimation of the concentrations of radionuclides in water.

Insufficient information was available to evaluate air sampling equipment and procedures. Although the relative contributions from airborne resuspension of radioactive materials to dose are believed to be minor, it should be noted that the occurrence of airborne resuspension, particularly during agricultural activities or dry periods, cannot be excluded.

Rapid screening and sophisticated techniques used locally for monitoring commercially available food from production to consumption appeared to be satisfactory. The relevant instrument calibration techniques could not be evaluated sufficiently by the Project owing to the lack of detailed technical information.

INDEPENDENT PROJECT SURVEYS

A variety of surveillance methods were used in the surveyed contaminated settlements and the surveyed control settlements to estimate surface contamination. The ranges of average values of surface contamination due to the deposition of caesium on the ground given in the official maps made available to the Project were corroborated. On the basis of the limited number of soil samples independently analysed for plutonium and strontium, the results for plutonium were found to correspond to the reported estimates, whereas a potential for overestimation in the reported data for strontium was identified.

The radioactive contamination of drinking water resources that were sampled in the surveyed contaminated settlements was found by the Project team to be significantly lower than the intervention levels established by the authorities.

The radioactive contamination of food samples was found to be in most cases below the intervention levels established by the responsible authorities in the settlements surveyed. In some settlements, milk from individual farms and food collected in natural areas in contravention of official recommendations could be contaminated above these levels.

Recommendations

Local laboratories should, as is customary, be confidentially notified of the Project findings of relevance for them and should take appropriate remedial actions where needed. Local laboratories which have participated in the intercomparison exercise should be informed confidentially of their performance so that they can rectify problems where necessary.

Quality assurance programmes to assure consistently reliable results should be in place in local laboratories. These laboratories should participate regularly in international intercomparison programmes and international intercalibration exercises.

A programme should be established to assess the significance of 'hot spots'. Research programmes on the characteristics of hot particles and their occurrence in the environment are warranted and should be continued.

Water sampling and analytical techniques should be improved to comply with established procedures. The potential for long term contamination of water bodies, possibly leading to contamination of the aquatic food chain, should be investigated. Research should be planned to study radionuclide behaviour in ecosystems, and desorption of strontium from sediments in surface water bodies and its impact on agriculture through irrigation practices.

It may be advantageous to consider the future use in the USSR of validated models to predict radionuclide levels in food. The use of these models could be cost effective in the long term and reduce the need for extensive sample analysis.

All data from the BSSR, the RSFSR and the UkrSSR related to radiological contamination should be shared with the USSR Central Data Bank in Obninsk so as to be made available to all Republics. All such information should also be made available to relevant institutes and institutions.

A programme should be implemented to derive more detailed official large scale contamination maps.

A collaborative programme of air sampling and analysis should be established between the local laboratories and the network of international laboratories set up by the IAEA Laboratory at Seibersdorf in order to obtain more definitive information on the relevance of the resuspension and inhalation pathways.

Chapter Three: Radiation Exposure of the Population

The Problem

Many people living in the areas affected by the Chernobyl accident remain anxious about the radiation exposure situation. Information on radiation risk is not well understood by the public and there is little grasp of the magnitude of the additional risk imposed by the post-Chernobyl contamination.

In the first few weeks after the accident, the significant radiation exposure to the population was due to the ^{131}I radionuclide. This could have been inhaled from the plume, though that represented only a minor pathway for population exposure. More important were the drinking of milk from cows grazing on contaminated pastures and the consumption of contaminated leafy vegetables.

Increasingly, as time passed, the largest proportion of the exposure arose from the ^{137}Cs radionuclide as a result of both exposure to external irradiation from surface contamination and internal exposure resulting from the consumption of contaminated food. It is difficult to be precise about how much radiation dose has already been received or will be received. Variations in soil conditions and in eating habits obviously render precision impossible and make the evaluation of past and future exposure difficult.

Key questions are:

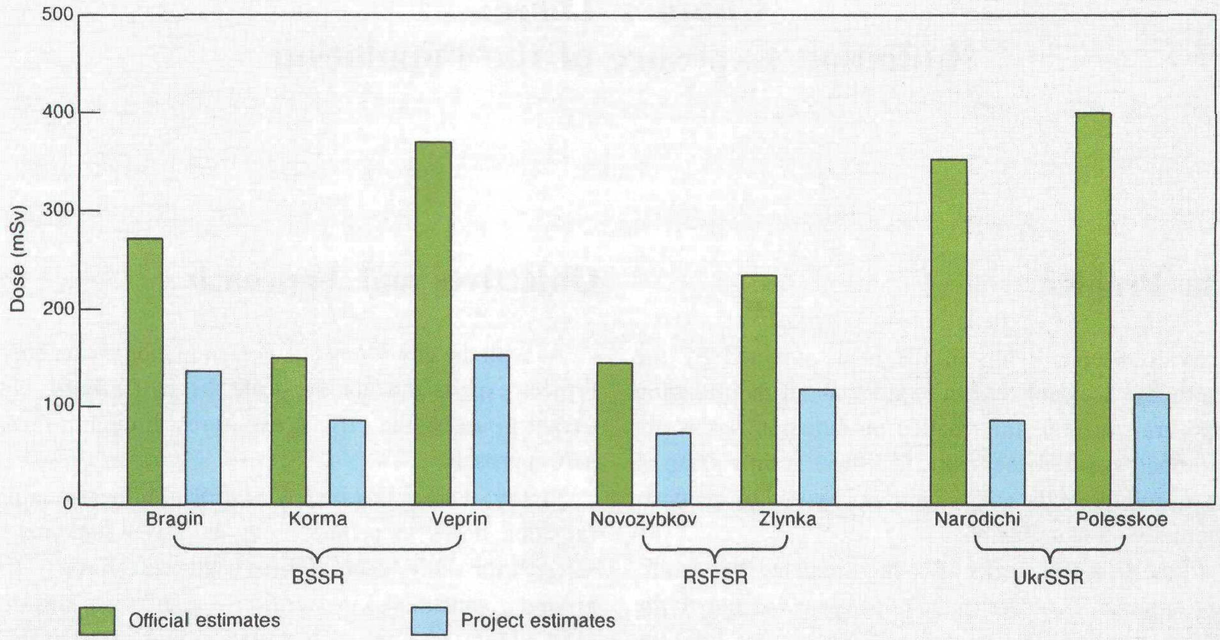
- How accurate were the official estimates of radiation exposure?
- What were the radiation exposures to the population in the early days after the accident?
- What are the current and future radiation exposures to those remaining in the affected areas?

Objectives and Approach

As with the environmental contamination evaluation, Project experts did not duplicate the past efforts, but sought to assess the official exposures through a three part approach.

Firstly, there was a review of official information on radiation doses to people living in seven settlements selected for study. Each of these settlements has a ^{137}Cs ground contamination greater than 555 kBq/m^2 (15 Ci/km^2) and in each instance non-contaminated food is provided commercially and there is a ban on the consumption of locally produced food. The Project teams visited over twenty institutes and government ministries in the BSSR, the RSFSR and the UkrSSR, where they examined and discussed dose calculation methodology. Attempts were made to reconstruct the dose estimates using the official information provided and direct discussions with local experts. However, this work was hampered by gaps in information, particularly in regard to the methods used to estimate ^{131}I thyroid doses and past levels of caesium contamination in food.

Secondly, the Project teams assessed the radiation exposure of the selected populations using internationally recognized methods and their own independently compiled database obtained through extensive fieldwork in mid-1990. They measured external radiation exposures for some 8000 residents and performed whole body monitoring of 9000 individuals for internal contamination. The whole body measurements were validated in French and Austrian laboratories and in the IAEA Laboratory at Seibersdorf.



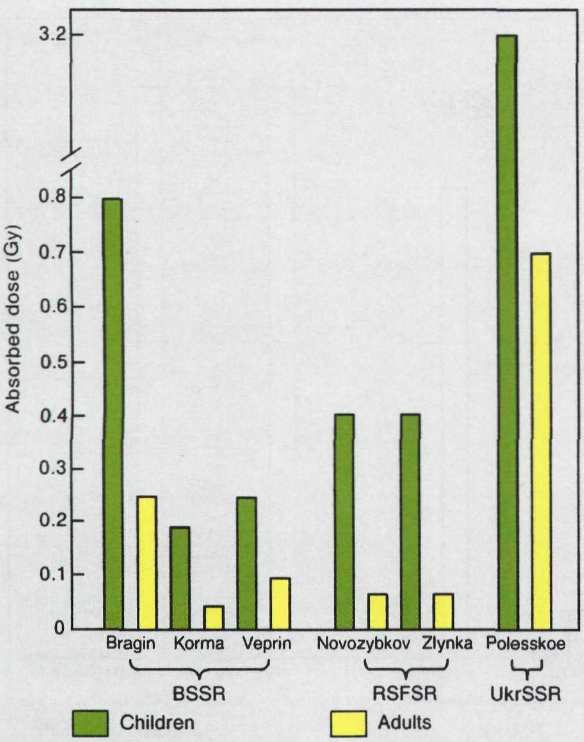
Comparison of Project reconstructed estimates with official estimates for radiation doses to the population in selected settlements. *From the Project review of official dose estimation methods, it was concluded that the official procedures for estimating doses were scientifically sound and that the methodologies used were intended to overestimate the doses. As illustrated here for seven surveyed settlements in the BSSR, the RSFSR and the UkrSSR, the Project reconstructed estimates for internal and external doses due to caesium and strontium were lower by a factor of 2–3 than the values officially reported by the Institute of Biophysics, Moscow.*

Finally, the independent Project estimates were compared with the official dose values. While there are shortcomings in extrapolating exposures from the Project's relatively small population samples, the information is adequate for a valid assessment of the overall population radiation exposure. Although some of the official reports lack clarity with respect to mathematical formulation and the selected values of parameters, the basic scientific assumptions in the dose calculations were found to be sound.

Work in Detail

REVIEW OF OFFICIAL DATA AND METHODOLOGY

Although Project experts obtained reasonable amounts of information from official data on environmental contamination and the radiation exposure of the population, the information was not sufficient to allow them to make calculations of individual radiation doses to residents. During the international review it was not



Official estimates of absorbed dose to the thyroid from radioiodine exposures. *Since the short lived radioiodines had completely decayed by the time of the international assessment, Project teams were unable to independently verify the doses officially reported by the Institute of Biophysics, Moscow. The reported doses were based both on thyroid measurements made during the early stage after the accident and on assumptions concerning the intake of food and milk contaminated by radioiodine. Local scientists are re-evaluating the results of their measurements made during this early stage. As illustrated here, the absorbed thyroid doses reported in 1989 for six settlements in the BSSR, the RSFSR and the UkrSSR indicated mean doses for children (from birth to seven years) that vary from less than 0.2 Gy to 3.2 Gy. Absorbed dose is defined as the energy absorbed per unit mass of tissue.*

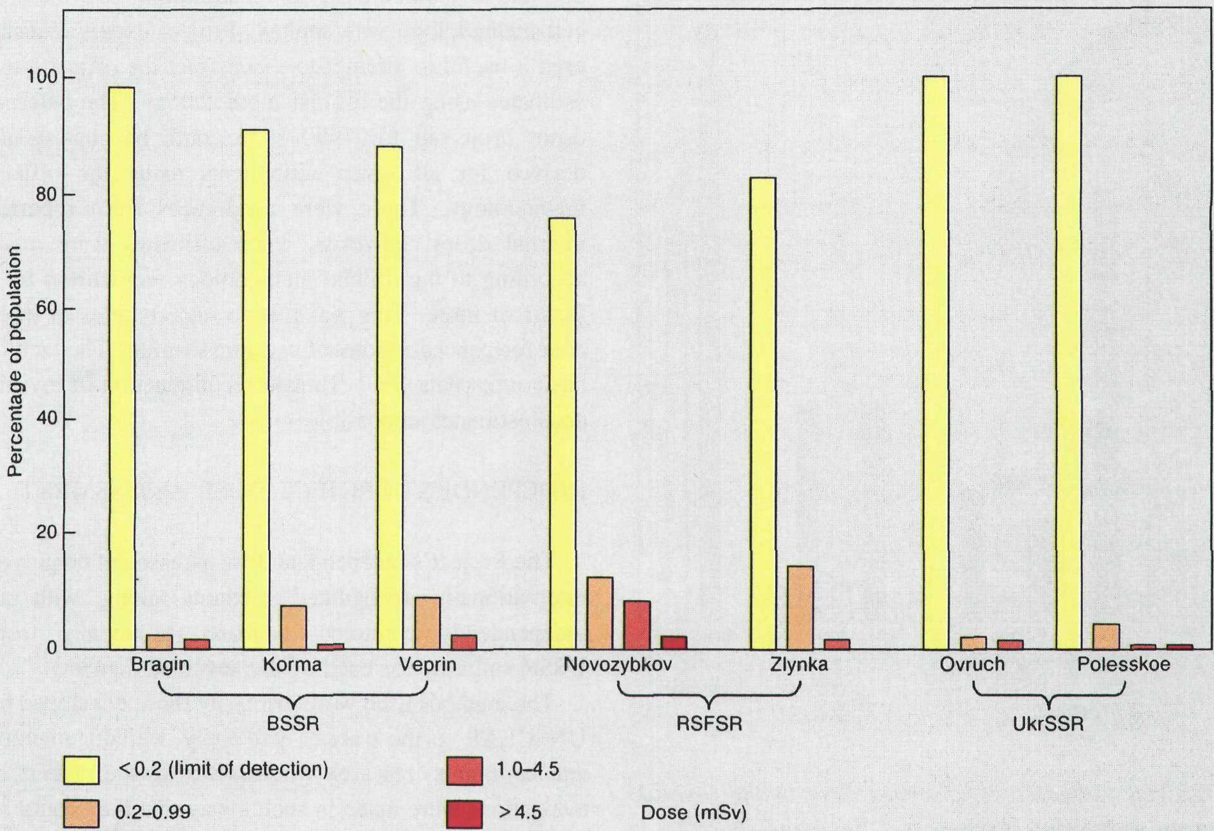
possible to obtain a clear demonstration of how the official methodology was applied. Project experts considered it useful to attempt to reconstruct the official dose estimates using the official methodology. The external doses projected for 1990–2056 could be consistently derived for all seven settlements using the official methodology. There were differences from reported internal doses, however, when estimates were made according to the official methodology, sometimes by a factor of three. This was due to uncertainties in input data for concentrations of caesium in milk. The lack of basic input data for ^{131}I made reconstruction of thyroid dose estimates impossible.

INDEPENDENT PROJECT DOSE ASSESSMENT

The Project's independent dose assessment employed internationally recognized methods along with an independently compiled database (principally from USSR sources) for each of the seven settlements.

The methods used were primarily those developed by UNSCEAR, as these are easy to apply, well documented and familiar to research workers worldwide. The dose evaluations were made in such a way that they could be compared with the official values reported for two periods: 1986–1989 and 1990–2056. Direct measurements were made of external and internal doses of people living in surveyed settlements. As in the official assessment, it was conservatively assumed that there would be no future restrictions on the consumption of locally produced food.

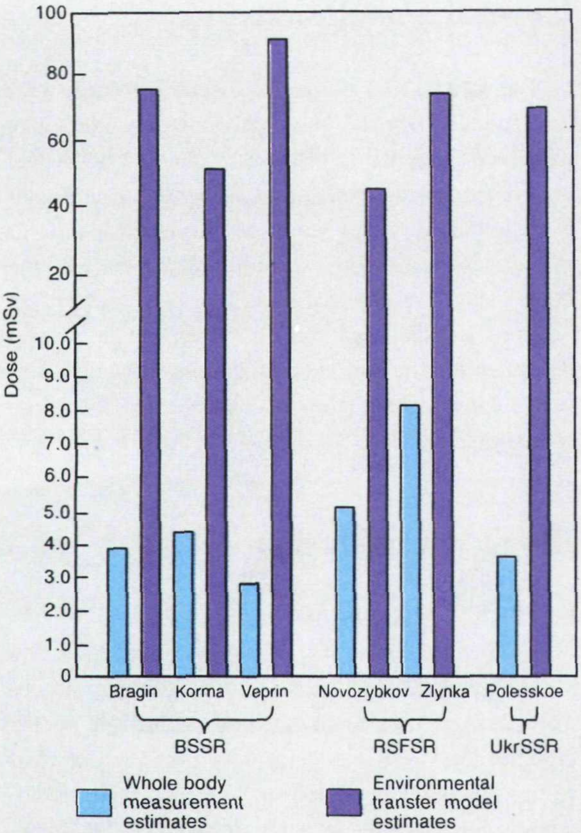
A total of 8000 personal radiation dosimeters (film badges) were distributed during mid-1990 to residents of the surveyed contaminated settlements. The results, which were independently read in a French laboratory, were given directly to the population in February 1991. While the intent was to cover all age groups in the population, most of the children were on holiday outside of these areas during the summer campaigns. The participants were instructed to carry the dosimeters in a pocket of their clothing on the upper half of the body and



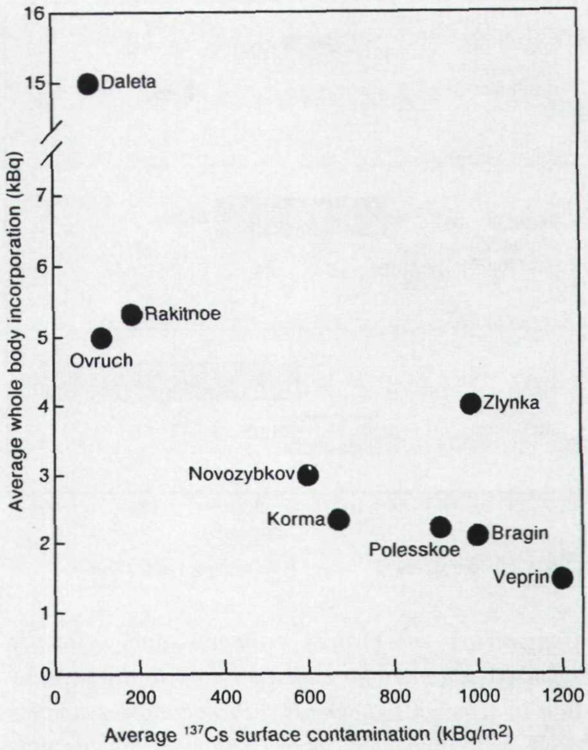
Project measurements of external dose to the population in selected settlements. *For independent measurement of external dose, 8000 film badge dosimeters were distributed to inhabitants of seven settlements in the BSSR, the RSFSR and the UkrSSR. As illustrated here, 90 per cent of the results were below the detection limit (of 0.2 mSv) for a two-month exposure period. The French Service central de protection contre les rayonnements ionisants (SCPRI) provided the dosimeters and measured their recorded doses.*

to place the instrument at the bedside during the night. Ninety per cent of the results were below the limit of detection. Higher measurements were recorded mainly for people living in the highly surface contaminated areas or working for long periods in open fields or forests. In the rare cases of unusually high values, it is suspected that the dosimeters may have been improperly used.

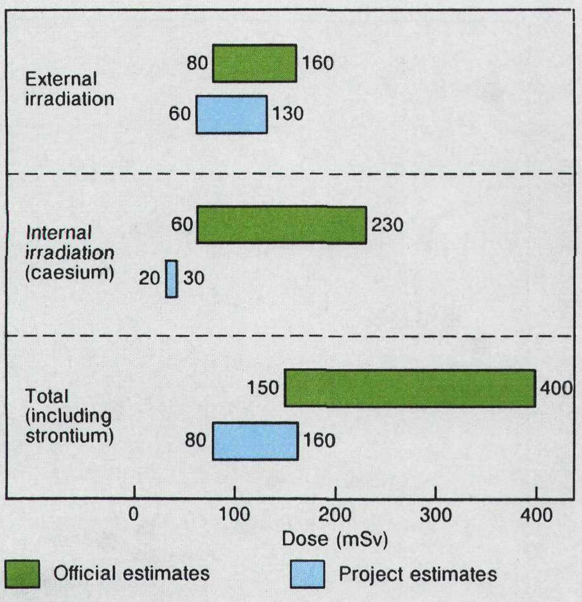
About 9000 people were monitored for internal irradiation in mid-1990. A mobile laboratory equipped with four whole body counters measured caesium levels in residents of the seven surveyed contaminated settlements. The results of these whole body measurements indicate little relationship between the amount of ^{137}Cs ground contamination and the amount of caesium in the body.



Comparison of Project estimates of internal doses based on whole body measurements with results based on environmental transfer models. *A major Project field effort was the direct measurement of caesium in the body of local residents. More than 9000 inhabitants of settlements in the BSSR, the RSFSR and the UkrSSR were monitored using portable whole body counters provided by SCPRI. As illustrated here, the Project dose estimates are eight to thirty times lower than those derived by means of environmental transfer models. The differences reflect the impact of restrictions imposed on the consumption of food produced in the contaminated settlements. The environmental transfer model assumes no restrictions on local food consumption (and would therefore predict a higher caesium body content).*



Relationship between Project measurements of caesium incorporated in the body of selected populations and official values for caesium surface contamination. *Project results from whole body counting indicated that there is not a direct relationship between the amount of caesium incorporated in the body of people living in the surveyed areas and the official values for surface contamination in those areas. As illustrated here, high levels of body contamination were found for residents of the settlements of Ovruch, Rakitnoe and Daleta in the UkrSSR, where the surface contamination is lower than in the other settlements surveyed. These high levels are probably due to the high transfer factor between soil contamination and food contamination in this area of the UkrSSR, and could indicate non-compliance with official recommendations regarding the consumption of locally produced food and milk.*



Comparison of Project estimates and officially reported estimates for radiation dose to the population in selected settlements. *Project dose estimates derived independently were compared with the official values for the population in the selected settlements as reported by the Institute of Biophysics, Moscow. As illustrated here, the Project estimates were lower than the officially reported dose estimates. Overall, there is general agreement within a factor of 2–3 (see footnote 5).*

COMPARISON OF DOSE ESTIMATES

The final step was the comparison of the dose estimates derived independently by experts and the officially reported values for the population in the surveyed contaminated settlements. In all cases the independent estimates were lower than the officially reported dose values, but overall there is general agreement to within a factor of 2–3.

General Conclusions

The official procedures for estimating doses were scientifically sound. The methodologies that were used were intended to provide results that would not underestimate the doses. Independent measurements in individual residents monitored for external and for internal exposure from caesium incorporated into the body yielded results that would be predicted on the basis of calculational models. Independent Project estimates for the surveyed contaminated settlements were lower than the officially reported dose estimates[3].

Detailed Conclusions

EXTERNAL EXPOSURE

The external exposure due to deposited radionuclides is, in most areas, the most significant contributor to dose, especially in those areas where food restrictions have been applied. The reported methodology for calculations of external dose is being confirmed by local measurements using thermoluminescence dosimetry.

Independent measurements of external exposure were carried out under the auspices of the IAEA for the Project. Eight thousand film badge dosimeters were distributed to residents of seven settlements. Ninety per cent of the results were below the detection limit of 0.2 mSv for a two month exposure period. This result is in agreement with what would be expected on the basis of calculational models.

[3] These estimates were derived on the basis of doses due to ^{137}Cs and ^{90}Sr; where appropriate, shorter lived isotopes of caesium and strontium were also taken into account.

INTERNAL EXPOSURE

Doses from incorporation of caesium in the first four years after the accident were estimated by the authorities on the basis of measurements of incorporated caesium, including both ^{134}Cs and ^{137}Cs. The procedure for estimating doses from these measurements is in accordance with that used in the independent evaluations made under the Project.

Official estimates of projected doses due to the intake of caesium are based on a number of influencing factors, including an assumed half-time of 14 years for ^{137}Cs in the environment. This assumption is designed to ensure that doses are not underestimated and is prudent.

Official estimates of doses due to the intake of strontium in the first four years after the accident were based on a metabolic model and measurements of strontium in foods, or on an assumed ratio of strontium to caesium in foods if no data on strontium were available.

Official estimates of projected doses due to the intake of ^{90}Sr in the diet were made on the assumption of an environmental half-time of 10 years; this assumption was not referenced, but is stated to be derived from experience gained after the accident at a nuclear materials production plant in Kyshtym in the USSR in 1957.

On the basis of the results of an intercomparison programme with the participation of local laboratories and the IAEA Laboratory using standardized phantoms, it can be concluded that the accuracy obtained in local whole body measurements for caesium is adequate for radiological protection purposes.

Whole body counting of caesium was carried out under the auspices of the IAEA for the Project and covered more than 9000 people in nine settlements. The results indicated generally lower body contents of caesium than would be predicted on the basis of most models of environmental transfer, dietary intake and metabolism. Similar results for whole body counting of caesium have been reported in other countries.

Absorbed thyroid doses due to iodine were officially reported on the basis of thyroid measurements made in the early stages after the accident and assumptions concerning intake. Mean absorbed thyroid doses for children from birth to seven years old were officially reported to vary from less than 0.2 Gy to 3.2 Gy for seven surveyed contaminated settlements.[4] However, since the iodine had completely decayed by the time of the Project, no independent verification of the reported absorbed thyroid doses was possible.

DOSE ESTIMATE COMPARISON

Independent estimates of doses were made for the surveyed contaminated settlements on the basis of average deposition results. It could not be assumed that such generalized dose estimation assumptions or environmental modelling calculations would accurately reflect the local soil conditions, agricultural practices and living habits in the surveyed contaminated settlements but the results could be expected to provide a general basis for comparisons.

The ranges in the estimates of 70 year (1986–2056) doses were as follows:

Independent estimates for the surveyed contaminated settlements:

External dose	60–130 mSv
Internal dose (caesium)	20– 30 mSv
Total (including strontium):	80–160 mSv

[4] The maximum reconstructed absorbed thyroid dose (in Bragin) was officially reported as 30–40 Gy.

Officially reported estimates for the same settlements:

External dose	80–160 mSv
Internal dose (caesium)	60–230 mSv
Total (including strontium):	150–400 mSv

Independent Project estimates for the surveyed contaminated settlements were lower than the officially reported dose estimates. Overall, there is agreement to within a factor of 2–3 between the independent estimates and the officially reported estimates.[5]

Recommendations

The official procedures for dose assessment reported to the Project use deterministic models that are designed not to underestimate doses. Probabilistic dose assessment methods should be developed so that more realistic estimates of dose are eventually available and uncertainties in the calculation are fully assessed.

Over the next few decades it should be possible to extend scientific knowledge of environmental transfer factors by studies in the contaminated areas of concern. Measurement of external exposure rate, caesium body burden and the caesium and strontium content of foodstuffs should be continued.

Although the potential relative contributions from resuspension to dose are believed to be minor, even for outdoor workers, doses should be assessed for critical groups such as agricultural workers.

Local scientists should participate more actively in international dose assessment validation studies. Such activities include intercomparisons of environmental transfer models and internal and external dosimetry intercomparisons.

Local scientists should participate more actively in international programmes on both the formal level (for example, through attendance at seminars, symposia and conferences) and the informal level to provide an exchange of information on technology that can be applied to the effective solution of dosimetric problems. Support should be given for specialists to gain experience working in foreign laboratories.

[5] These conclusions were drawn on the basis of estimated or reported doses from external exposure due to all relevant radionuclides and internal exposures due to ^{134}Cs, ^{137}Cs and ^{90}Sr. Doses to the thyroid from ^{131}I and other short lived isotopes of iodine and their precursors have also been considered.

Chapter Four: Health Impact

The Problem

The suspected health impact of the Chernobyl accident has unquestionably been of overriding concern among the population. There had been continuing reports of a higher incidence of illness among those residing in the affected areas. No doubt, the heightened sensitivity to health issues led to an increased registration of complaints and a greater number of diagnoses of both serious and non-serious illnesses.

Public and professional uncertainty and concern centred on the following questions:

- What health problems were related to the Chernobyl accident?
- What health effects were due directly to radiation exposure?
- What health effects may be expected in the future?

Objectives and Approach

In an attempt to assess the reported increases in illness attributed to the Chernobyl accident and to deal with the concerns, a two step approach was used in the Project. The first step was to review official data at key medical centres and institutes. The next step was to examine people in both surveyed contaminated and surveyed control settlements and to compare the results. Because medical data before 1986 are sparse, the health of inhabitants from the surveyed contaminated settlements had to be compared with that of a similar population living in surveyed control settlements where contamination levels are lower but socioeconomic conditions are similar. The examination results were reviewed by Project teams of doctors and epidemiologists, who employed a limited version of a commonly used epidemiological approach to determine the health risk. Additionally, a nutrition expert reviewed data in Moscow and the three Republics, and a field team visited 13 settlements to conduct total diet studies.

Any health effects study initiated four years after the accident was bound to have weaknesses and limitations and this one was no exception. To begin with, the study was limited to the population continuing to be exposed to radiation from the accident, namely those who remain in the surveyed contaminated areas. It would not have been possible to search out and conduct medical examinations on those who had left.

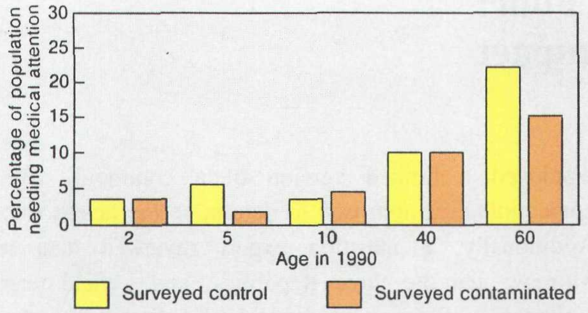
The study concentrated on small to moderate size rural villages and towns since these were located in areas of higher contamination than the larger cities. The type of settlements and the population groups studied cannot be taken as entirely representative of the situation in the larger cities of the affected areas. Nutritional differences due to variations in food availability and consumption would undoubtedly contribute to differences in health status.

There were serious limitations in the data officially provided. Internal correlation of the diverse data as well as correlation with the Project data were extremely difficult because of deficiencies in the equipment and methodology that had been used.

Work in Detail

SELECTION OF SURVEYED CONTAMINATED AND SURVEYED CONTROL SETTLEMENTS

The selection of the settlements was made by the medical task force. The settlements were chosen to

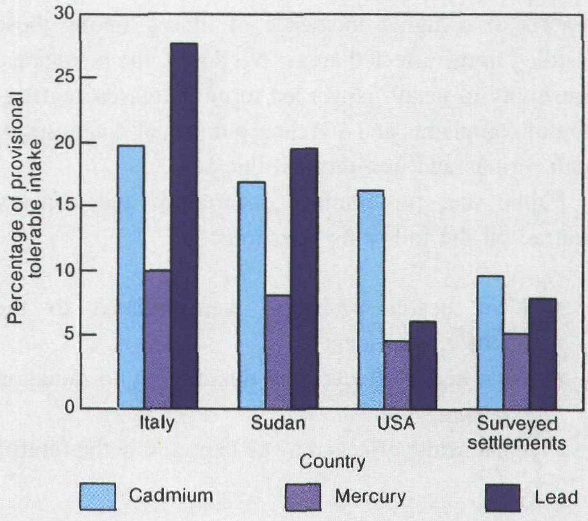


Project assessment of the general health of the population in selected settlements. *The Project assessment of reported increases in illness attributed to the Chernobyl accident included an investigation of the general health of the population in selected settlements. Independent medical examinations of inhabitants of both surveyed contaminated and surveyed control settlements revealed no health disorders that could be attributed directly to radiation exposure, but did indicate significant non-radiation-related health disorders among the adult population. As illustrated here, Project results indicated that 10–15 per cent of the adult population examined in both surveyed contaminated and surveyed control settlements should be referred to a physician for follow-up medical care.*

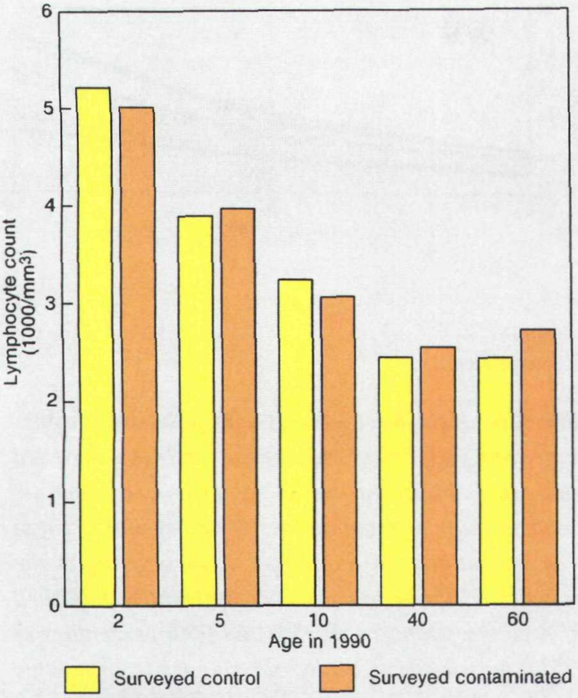
be representative of the various communities in the study region (ranging in population from 3000 to 15 000). The surveyed control settlements had socio-economic structures similar to the seven surveyed contaminated settlements.

Since the field teams could examine only a small portion of the population it was necessary to choose a representative group. A statistical sampling scheme was designed to take into account the anticipated clinical health problems.

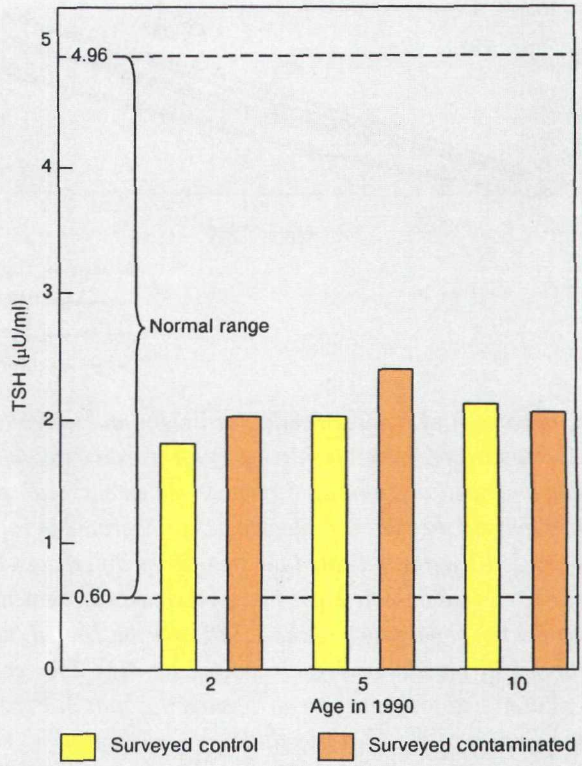
In smaller villages patients were selected by year of birth, in larger villages by month and year of birth. The aim was to examine various age groups of 20 people each, which, depending on the size of the settlement, represented between 10 per cent and 80 per cent of the population. Approximately 250 people were examined in each settlement. In all, 1356 people were examined.



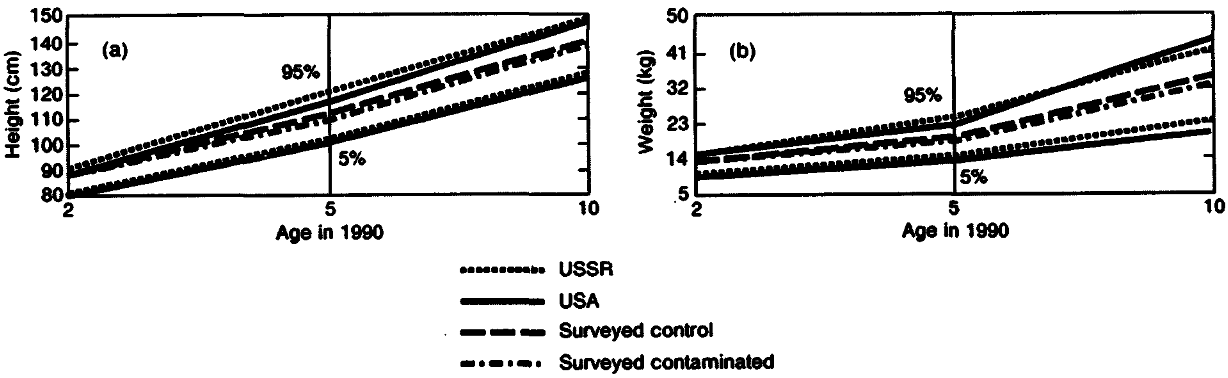
Dietary intake of toxic elements of inhabitants of surveyed settlements compared with that of populations of other countries. *Project analytical results for food, tissue and environmental samples lent no support to public concerns about the possible environmental dispersion of toxic elements used at the Chernobyl plant site shortly after the accident. As illustrated here, the dietary intake of cadmium, mercury and lead by people surveyed by Project teams was low compared with that recorded for people in Italy, Sudan and the United States of America. All values are expressed as percentages of the relevant provisional tolerable intake defined by WHO and FAO. The data are calculated for 80 kg body weight.*



Project results for absolute lymphocyte count in residents of selected settlements. *Project haematological investigations of residents of selected settlements found some young children with low haemoglobin levels and low red cell count. However, there were no statistically significant differences between values for any age group of those examined in surveyed contaminated and surveyed control settlements. No difference was found between the settlement populations when leucocytes and platelets were examined. As illustrated here, independent field counting of the absolute lymphocyte level in people of all ages does not reveal any marked difference in levels between surveyed contaminated and surveyed control villages. Nor are there any significant variations from data of other countries. (The normal range varies with age.) The immune systems of those examined (as judged from the lymphocyte level and the prevalence of other diseases) do not appear to have been significantly affected by the accident.*



Project results for thyroid stimulating hormone of children in selected settlements. *Owing to the susceptibility of the thyroid gland to radioiodine exposure, the international assessment gave particular investigative attention to possible thyroid disorders in individuals. Project results for thyroid sizes and size distribution and thyroid nodules in those examined are similar to those reported for populations in other countries. No statistically significant differences were found in those examined for thyroid stimulating hormone (TSH) or for the thyroid hormone (free T4). As illustrated here, independent analyses using radioimmunoassay methods found no abnormalities in the thyroid function of children 2–10 years old, nor was there any statistically significant difference observed between the thyroid functioning of children examined from the surveyed contaminated and surveyed control settlements.*



Comparison of Project results for height and weight of children in selected settlements with published norms. *A comparison of the results of Project examination of the growth patterns of children in both the surveyed contaminated and surveyed control settlements with published norms indicated that the children are generally healthy and their diet is adequate. As illustrated here, independent medical examinations of nearly 800 children aged 2–10 years indicated no significant differences in (a) the height and (b) the weight of those living in the surveyed contaminated and surveyed control settlements. Growth rates for both groups are well within published norms for populations of the USSR and the United States of America. Data for the 5th and 95th percentiles of the USSR population were reported by A.F. Zyb, et al., "The measurement of thyroid gland size in healthy children and teenagers by ultrasound methods",* Paediatrics, *May 1990 (in Russian). Data for the 5th and 95th percentiles of the USA population were reported by P.V. Hamill, et al., "Physical growth: national center for health statistics percentiles",* American Journal of Clinical Nutrition, *March 1979, Vol. 32, No. 3, pp. 607–629.*

REVIEW OF OFFICIAL DATA

The first step in the assessment of the general health situation in the surveyed contaminated areas was to review and locate the available medical data dealing with the population of interest to this study. Two Project doctors met with 73 different scientists during 23 separate meetings in Moscow, Kiev and Minsk. During these meetings, in addition to collecting the information that would provide the basis for the review of the USSR data, the doctors discussed the goals and the outline of the Project. This laid the groundwork necessary for the visits of three international teams of experts to conduct independent medical examinations in the three Republics affected by the Chernobyl accident. These data were reviewed at a later date by seven doctors and epidemiologists that visited the relevant institutions in Moscow, Kiev, Minsk and Obninsk.

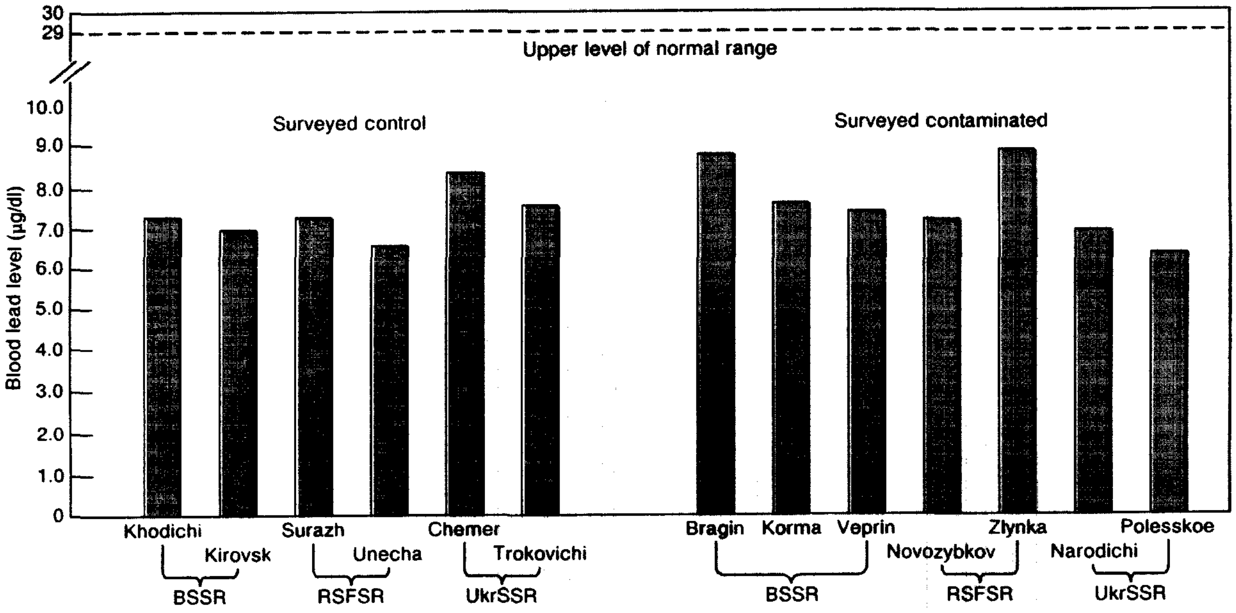
Concurrently, a review of the available nutritional data and a limited independent assessment of the nutritional status of the population were conducted. A nutrition expert visited institutions in Moscow, Kiev, Gomel and Minsk to review the data and a team visited 13 settlements in the three Republics to conduct a total diet study.

INDEPENDENT MEDICAL EXAMINATIONS

The largest part of this assessment was carried out through missions by three medical field teams, each of which spent two weeks conducting medical examinations of the population. These examinations were made for evaluation purposes only. Any persons found to be in need of further examination or treatment were referred to local health authorities. In many cases the results of the Project examinations were entered into the local clinical medical records. The populations sampled were statistically selected and rigorous quality control on the data collected was implemented.

These missions were designed to address the medical concerns of the population and the perceived health effects as outlined by local scientists and physicians, as well as to look for radiation effects that had been documented in other studies unrelated to Chernobyl. Each team included specialists in radiation effects, pediatrics, haematology, thyroid diseases, ultrasound examination and internal medicine, as well as representatives from WHO. On one trip there was also an expert in psychological and psychiatric disorders. The areas studied were divided roughly into:

— Past medical history
— General psychological state
— General health condition
— Cardiovascular status
— Growth parameters
— Nutrition
— Thyroid structure and function
— Haematology and immune system deficiencies
— Neoplasms
— Cataracts
— Biological dosimetry
— Foetal and genetic anomalies.



Project results for blood lead levels in children from selected settlements. *Project analyses of lead levels in the blood of children from selected settlements indicated that environmental exposure to lead was low. As illustrated here, the analyses of 185 samples taken from children aged 2-5 years in both surveyed contaminated and surveyed control settlements were found to be well within the normal range (up to 29 µg/dl).*

General Conclusions

There were significant non-radiation-related health disorders in the populations of both surveyed contaminated and surveyed control settlements studied under the Project, but no health disorders that could be attributed directly to radiation exposure. The accident had substantial negative psychological consequences in terms of anxiety and stress due to the continuing and high levels of uncertainty, the occurrence of which extended beyond the contaminated areas of concern. These were compounded by socioeconomic and political changes occurring in the USSR.

The official data that were examined did not indicate a marked increase in the incidence of leukaemia or cancers. However, the data were not detailed enough to exclude the possibility of an increase in the incidence of some tumour types. Reported absorbed thyroid dose estimates in children are such that there may be a statistically detectable increase in the incidence of thyroid tumours in the future.

On the basis of the doses estimated by the Project and currently accepted radiation risk estimates, future increases over the natural incidence of cancers or hereditary effects would be difficult to discern, even with large and well designed long term epidemiological studies.

Detailed Conclusions

CURRENT HEALTH EFFECTS ATTRIBUTED TO RADIATION

Reported adverse health effects attributed to radiation have not been substantiated either by those local studies which were adequately performed or by the studies under the Project.

Many of the local clinical investigations of health effects had been done poorly, producing confusing, often contradictory results. The reasons for these failures included: lack of well maintained equipment and supplies; poor information through lack of documentation and lack of access to scientific literature; and shortages of well trained specialists. Nevertheless, despite these obstacles, a number of the local clinical studies were carefully and competently performed and the Project team was able to corroborate the results in most cases.

SPECIFIC RESULTS OF PROJECT FIELD STUDIES

Field studies were undertaken of continuous residents of rural surveyed contaminated settlements (with surface contamination higher than 555 kBq/m^2 (15 Ci/km^2) due to caesium) and surveyed control settlements of 2000 to 50 000 persons, using an age matched study design. The studies were performed in the second half of 1990 and relate to the health status at that time. The strategy of the study, to elucidate major health problems identified by general clinical examinations and sophisticated laboratory tests, was adequate to answer most concerns of the population. There was no exhaustive testing of each individual, and the study did not resolve all questions relating to potential health effects.

Psychological Disorders

There were many important psychological problems of anxiety and stress related to the Chernobyl accident and in the areas studied under the Project these were wholly disproportionate to the biological significance of the radioactive contamination. These problems are prevalent even in the surveyed control settlements. The consequences of the accident are inextricably linked with the many socioeconomic and political developments that were occurring in the USSR.

A large proportion of the population have serious concerns; these people are not acting in an irrational way that could be termed radiophobic. The vast majority of adults examined in both the surveyed contaminated settlements and the surveyed control settlements visited either believed or suspected they had an illness due to radiation.

Most adults in both surveyed contaminated and surveyed control settlements were native to the local area and virtually all have stated that they have lived in the settlements since birth and therefore relocation is a major concern. While only about 8 per cent of adults in surveyed control settlements wanted to relocate, the adults in the surveyed contaminated settlements were so concerned that 72 per cent wanted to relocate. The percentages of the population who think that the Government should relocate the whole population are higher: 20 per cent and 83 per cent, respectively.

General Health

The children who were examined were found to be generally healthy. Field studies indicated that there were a significant number of adults in both surveyed contaminated and surveyed control settlements with substantial medical problems, with 10 per cent to 15 per cent (excluding hypertensive adults) requiring medical care.

Cardiovascular Disorders

There were many hypertensive adults; however, the statistics related to both systolic and diastolic blood pressure were similar for both surveyed contaminated and surveyed control settlements, and both were comparable with published values for Moscow and Leningrad.

Nutrition

Diet appeared to be limited in range but adequate. No significant differences in reported eating habits were found between surveyed contaminated and surveyed control settlements. No detrimental effects on growth due to voluntary or official dietary restrictions imposed as a result of the accident were found. There were no significant differences between the growth rates of children in surveyed contaminated and surveyed control settlements, and the rates for both groups are well within published USSR and international norms. Adults were generally overweight by international standards in all areas studied. Intake and excretion of iodine were found to be at the low end of the acceptable range. Most other dietary constituents and components were found to be adequate; however, vitamin intake was not examined. Dietary intakes of toxic elements (lead, cadmium, mercury) were low in comparison with those reported for many other countries and were well below the maximum tolerable intake levels specified by international organizations. Blood lead levels were also investigated and were found to be well within the normal range.

Thyroid Gland Disorders

No abnormalities in either thyroid stimulating hormone (TSH) or thyroid hormone (free T4) were found in children examined. No statistically significant difference was found between surveyed contaminated and surveyed control settlements for any age group.

Mean thyroid sizes and the size distributions were the same for populations of surveyed contaminated and surveyed control settlements. Thyroid nodules were extremely rare in children; they occurred in up to 15 per cent of adults in both surveyed contaminated and surveyed control settlements. Project results are similar to those reported for populations in other countries.

Haematology

Some young children with low haemoglobin levels and low red cell counts were identified. However, there were no statistically significant differences between values for any age group of the population in surveyed contaminated and surveyed control settlements. No difference was found between the populations when leucocytes and platelets were examined. Immune systems (as judged from the lymphocyte level and the prevalence of other diseases) do not appear to have been significantly affected by the accident.

Neoplasms

Review of USSR data indicated that reported cancer incidence had been rising for the last decade (starting before the Chernobyl accident occurred) and has continued to rise since the accident. The Project team considered that there had been incomplete reporting in the past and could not assess whether the rise is due to increased incidence, methodological differences, better detection and diagnosis or other causes. The data did not reveal a marked increase in leukaemia or thyroid tumours since the accident; however, owing to the classification scheme used and other factors, the possibility of an increase in the incidence of these tumours cannot be excluded. Only hearsay information relating to such tumours was available.

Radiation Induced Cataracts

There was no evidence of radiation induced cataracts in the general population.

Biological Dosimetry

Chromosomal and somatic cell mutation assays are still being completed on adults who had worked outdoors, since their exposures were assumed to be the highest. So far, no significant difference has been found between adults living in surveyed contaminated and surveyed control settlements. The data obtained were consistent with the Project dose estimates.

Foetal and Genetic Anomalies

Review of USSR data for settlements in contaminated areas of concern as well as for the Republics as a whole indicated relatively high infant and perinatal mortality levels. These levels prevailed before the accident and appear to be decreasing. No statistically significant evidence was found of an increase in incidence of foetal anomalies as a result of radiation exposure.

POTENTIAL DELAYED HEALTH EFFECTS

Available data reviewed do not provide an adequate basis for determining whether there has been an increase in leukaemia or thyroid cancers as a consequence of the accident. The data were not detailed enough to exclude the possibility of an increase in the incidence of some tumour types. On the basis of the doses estimated by the Project and currently accepted radiation risk estimates, future increases over the natural incidence of all cancers or hereditary effects would be difficult to discern, even with large and well designed long term epidemiological studies. Reported estimates of absorbed thyroid dose in children are such that there may be a statistically detectable increase in the incidence of thyroid tumours in the future.

Recommendations

GENERAL HEALTH AND POTENTIAL ACCIDENT CONSEQUENCES

The adverse health consequences of relocation should be considered before any further relocation takes place.

Consideration should be given to the introduction of programmes to alleviate psychological effects. These might include informational programmes for the public. There should also be educational programmes set up for teachers and local physicians in general preventive health care and radiation health effects.

The current policy of annual physical examinations is conceptually adequate for the health needs of the general population in the contaminated areas of concern. However, certain high risk groups (such as children with high absorbed thyroid doses) will need specific medical programmes based on their potential risks.

Energetic action should be taken to improve the standard of medical, diagnostic and research equipment and the availability of medical supplies, manuals and spare parts.

Clinical and research investigations should emphasize the use of appropriate control groups, standards and quality control procedures.

Improvements should be made in the statistical, data collection and registry systems used by local scientists by the adoption and application of internationally accepted standards and methods.

There should be increased opportunities for information exchange and greater availability of scientific literature for local health professionals.

POTENTIAL DELAYED HEALTH EFFECTS

In view of the limited resources available, the concept of the WHO Scientific Advisory Group on the Health Effects of Chernobyl, namely to concentrate on prospective cohort studies of selected high risk populations, should be endorsed. It is impractical, owing to the extreme difficulty and cost, to conduct long term studies or to evaluate all persons who live in the affected Republics.

GENERAL PUBLIC HEALTH ISSUES IN THE AFFECTED REPUBLICS

Action should be taken on adult hypertension and dental hygiene as major health issues. The need for continuing programmes for iodization of salt should be re-evaluated; if these are found to be necessary, the effectiveness of the chemical process should be assessed.

Chapter Five: Protective Measures

The Problem

A number of protective measures were instituted by the authorities after the accident to limit the radiation exposure of the population. These included early countermeasures (such as sheltering, administration of stable iodine and evacuation) introduced largely to deal with the effects from the plume of radioactive materials passing over areas near the reactor. Intermediate and long term countermeasures (such as relocation, restriction of foods, agricultural measures and decontamination) were taken to deal with lower, but still significant, levels of radiation from surface and soil contamination.

Situations posing radiation hazards can be divided into two categories:

- Situations that result from the introduction or modification of radiation *practices* that can therefore be anticipated in advance; these require inter alia the setting of dose limits to restrain the anticipated increase in the radiation exposure that will result from the practice; and

- Unforeseen, de facto situations, including post-accident contamination and emergencies, which call for *intervention* in the normal lives of the public to reduce the higher than normal radiation doses to levels as low as reasonably achievable under the prevailing circumstances.

Although international guidance and criteria on intervention existed before the accident, experience in their application was very limited, especially in the area of long term protective measures. The magnitude of the Chernobyl accident and the extent of the areas affected by it raised issues that had not been previously addressed. Inevitably, under these circumstances, an evolutionary approach had to be developed for the practical implementation of the criteria, especially for relocation. Because of this lack of previous experience this evolving process, which affected the lives of many people, caused many problems. Particular concern was expressed about the concept put forward by the USSR authorities of a 350 mSv 'lifetime dose limit'.

Decisions on protective measures became engulfed in the changing socioeconomic situation in the USSR. It was these socioeconomic factors that dominated the general thinking, almost to the exclusion of more detailed considerations about radiological protection principles.

Objectives and Approach

Project experts primarily examined those protective measures taken or proposed from 1990 onwards by the authorities. This was a central issue in the USSR request for an international study. A more limited evaluation was also made of measures taken prior to 1990, to understand how past actions may have influenced or constrained future options. These measures were compared with international recommendations and evaluated for their appropriateness.

The current international radiological protection principles for situations requiring intervention following an accident are as follows:

- The proposed intervention should do more good than harm, i.e. the reduction in the expected radiation harm resulting from the reduction in dose should be sufficient to justify the harm and costs, including social costs, of the intervention itself; and

- The form, scale and duration of the intervention should be optimized so that the net benefit achieved by the reduction in dose (i.e. the benefit from the reduction in the radiation harm less the harm associated with the intervention itself) is maximized.

The dose limits recommended internationally are intended for use in the control of practices and do not apply to intervention. The use of these or any other predetermined dose limits as the basis for deciding on intervention could involve measures out of proportion to the benefits obtained, which would conflict with the principle of justification. Therefore, the application of dose limits for deciding on the need for, or scope of, intervention is not recommended.

These principles guided the Project work on evaluating the protective measures.

Towards the end of the Project a number of 'decision conferences' were held with decision makers at both the Republic and All-Union levels to enable the decision problems to be structured efficiently and to clarify and summarize for the Project the socioeconomic and political factors that have influenced the decision making process in the affected Republics.

Work in Detail

EARLY COUNTERMEASURES

Sheltering, thyroid blocking by the administration of stable iodine and evacuation were introduced in varying degrees in the first days following the accident. The reported radiation levels which triggered these countermeasures were well below the threshold doses at which acute early effects of radiation occur.

Intervention levels for evacuation, in terms of dose levels projected over the first week after the accident, were established for both whole body and individual organ exposures.

People were allowed to continue living in areas only if the projected doses were less than the intervention level. The authorities introduced evacuation measures as soon as it was established that the predicted doses were likely to exceed the intervention level. If the dose rate on the first day after the accident exceeded 1 mSv/h (0.1 rem/h), evacuation was immediate and compulsory. In areas with a dose rate of 0.1–0.3 mSv/h (0.01–0.03 rem/h), only women and children were evacuated. Below a dose rate of 0.1 mSv/h (0.01 rem/h), no evacuation was introduced.

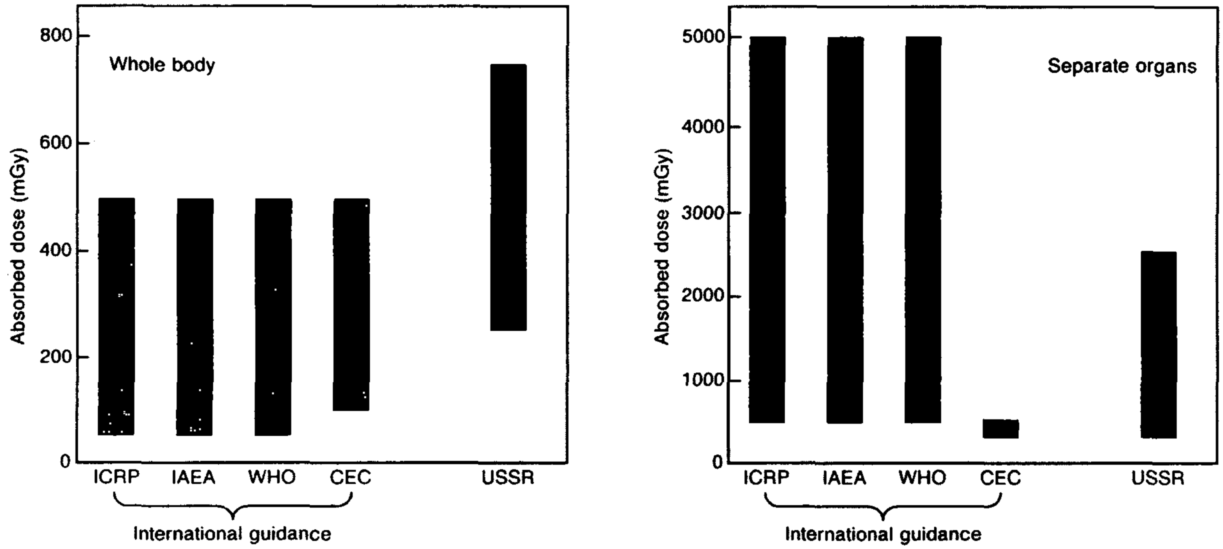
LONGER TERM COUNTERMEASURES: RELOCATION AND FOOD RESTRICTIONS

The current radiological protection task in the affected areas is complicated by the large extent of the areas contaminated and the belief of the population that they are living in conditions that are very dangerous. The Supreme Soviet of the USSR established a programme with financial compensation for the two-year period 1990–1992 for relocation and a number of measures to improve the living conditions in the affected settlements. Different relocation concepts have been proposed: they include 'temporary annual dose limits', 'lifetime dose limit' and a surface contamination concept. In addition, contamination levels for various foodstuffs are in force.

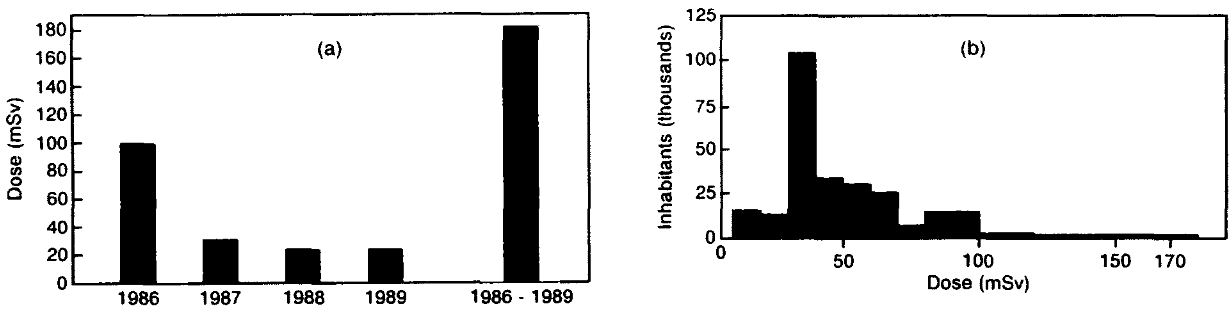
Relocation Measures

Temporary Annual Dose Limits

Following the accident, the Ministry of Health of the USSR, on the recommendation of its National Commission for Radiological Protection, implemented a previously prepared regulation establishing a temporary annual dose limit of 100 mSv (10 rem) for whole body irradiation of the population in the first year after an accident. The USSR Ministry of Health also approved temporary annual dose limits for the years 1986–1989.



Criteria for evacuation of the population in the early phase of the Chernobyl accident. *While the Project team was not able to investigate in detail many of the early protective actions taken by the responsible authorities, it was judged that the general response of the authorities was broadly reasonable. As illustrated here, the intervention levels of absorbed dose for evacuation applied in the early phase of the post-accident response by the authorities were consistent with general guidance prevailing at the time of the accident (the vertical columns indicate the upper and lower levels of the guidance values.)*



'Temporary annual dose limit' for the intermediate phase and reported estimated dose distribution. *During the intermediate phase of the post-accident response (1986–1989) new intervention levels of dose were established under the name 'temporary annual dose limits' (a). As illustrated here, the 'accumulated temporary dose limit' for 1986–1989 totalled 180 mSv. The officially reported dose estimates (b) for residents in areas with ground contamination greater than 15 Ci/km^2 (555 kBq/m^2) showed a distribution with an average dose much lower than 180 mSv.*

Lifetime Dose Limit

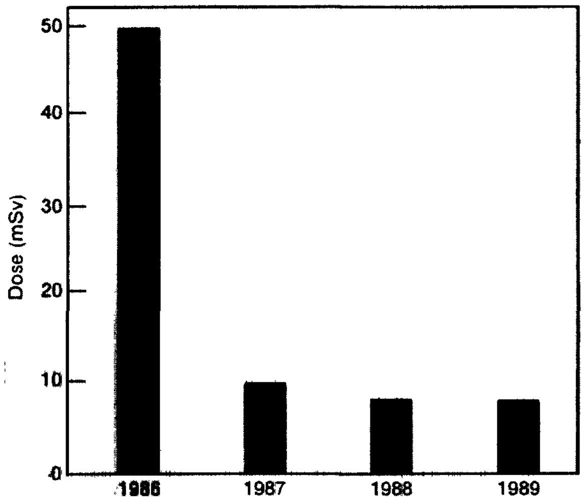
In late 1988 the USSR National Commission for Radiological Protection recommended a lifetime dose limit of 350 mSv (35 rem) as the intervention level for relocation. It was to be implemented beginning on 1 January 1990. This limit was defined as the total internal and external individual dose that would be accumulated by a child born in 1986 during a 70 year lifetime, and was to include the doses since 26 April 1986. The lifetime dose limit of 350 mSv (35 rem) was said to give a high degree of safety as it included doses received from the date of the accident. Doses from the past were included in order to reassure the public that there would be no measurable biological effects from the projected lifetime doses.

Surface Contamination Concept

In April 1990 the Supreme Soviet of the USSR introduced a surface contamination concept as a criterion for both relocation and improvement of living conditions in an attempt to move away from dose related concepts. In this programme, relocation would be compulsory for people living in areas with a caesium surface contamination level above 40 Ci/km^2 (1480 kBq/m^2). As part of the programme to improve living conditions, people living in areas with contamination levels in the range 15–40 Ci/km^2 (555–1480 kBq/m^2) would be paid compensation of 30 roubles per month and relocation would be obligatory for pregnant women and children and optional for others. The programme would provide compensation of 15 roubles per month to people living in areas with contamination levels in the range of 1-15 Ci/km^2 (37-555 kBq/m^2) but relocation would not be an option.

Food Restrictions

The intervention levels for foodstuffs apply to total food intake. In the first two months or so after the accident, the main source of internal radiation dose was ^{131}I, which was ingested mainly in milk from dairy herds grazing in contaminated pastures. In order to limit the iodine intake, temporary control levels were set for its content in milk and dairy products and strict radiological monitoring of all dairy products was started. Similar measures were taken to limit the intake of caesium (^{137}Cs) in food, which remained the most important source of radiation after the iodine had substantially decayed. Internal contamination was reduced by restrictions on the consumption of contaminated food. Maximum permissible levels of contamination in basic food products were set by the USSR Ministry of Health. In addition, the Republics and regions had the authority to set their own levels.



***Intervention levels of dose for food restriction.** The intervention levels of dose for food restriction established by the authorities were broadly consistent with international guidance prevailing at the time of the accident. The Project concluded that "higher values of intervention levels would have been justifiable". Moreover, "doses actually received ... were substantially lower than the prescribed intervention levels of dose, typically by a factor of 2–4".*

LONG TERM RELOCATION CRITERIA

Long term relocation concepts were established at first on the basis of a lifetime dose of 350 mSv (35 rem) as the intervention level for relocation, the so-called 'lifetime dose limit'. Subsequently, a surface contamination of 40 Ci/km^2 (1480 kBq/m^2) was introduced as the intervention level for relocation. The bases on which the criteria for relocation were derived were not wholly consistent with the principles currently recommended internationally. However, the International Advisory Committee concluded that "The protective measures taken or planned for the longer term, albeit well intentioned, generally exceed what would have been strictly necessary from a radiological protection viewpoint." The table gives estimates of dose averted for the various intervention concepts. The Committee concluded that "measures are not justified on radiological protection grounds; however, any relaxation of the current policy would almost certainly be counterproductive in view of the present high levels of stress and anxiety amongst inhabitants of the contaminated areas of concern and people's present expectations."

Criterion	Year of application	Level	Lifetime dose averted from external radiation (mSv)	Lifetime dose averted from external radiation and residual ingestion dose (mSv)
Temporary	1986	100 mSv per annum		
annual	1987	30 mSv per annum	~140	<240
dose	1988	25 mSv per annum	~130	<230
limit	1989	25 mSv per annum	~150	<260
Lifetime dose limit	1990	350 mSv lifetime	~ 60	<130
Surface	1990	>40 Ci/km^2 surface	~ 80	<160
contamination	1990	<15 Ci/km^2 surface	~ 30	< 80

Systematic monitoring of the levels of contamination of food products was also undertaken. There are three levels in this control system, ranging from expert monitoring provided by specialist organizations to mass monitoring by many different units in the food and agriculture industry.

A range of countermeasures has been developed and taken with the aim of permitting the production of food with contamination below maximum permissible levels; some of these measures have had the secondary benefit for agricultural workers of reducing the external dose from deposited contamination and the inhalation of resuspended radioactive materials.

DECISION CONFERENCES

The process of decision making for intervention purposes is extremely complex and involves many factors, including non-radiation-related factors. It was therefore thought appropriate to hold five decision conferences, one in each of the affected Republics, one at the All-Union level, and, subsequently, one at which representatives from the earlier conferences met to build a decision model that represented the main issues and concerns.

The main aims of these conferences were to identify the key socioeconomic and political issues influencing the protective measures and to illustrate the potential benefits of formal techniques for the resolution of complex problems. The choice of participants was a matter for the USSR and relevant Republic authorities.

Each decision conference began with a general discussion of the key issues and concerns. The following issues were regularly raised: the scale of the accident, the need for a safe living concept, health problems, stress, relocation, the lack of trust and understanding, the continuing risk from the 'sarcophagus' covering the damaged reactor and the risk of water pollution. There was a consensus concerning the attributes or criteria against which each strategy had to be evaluated. The medical effects arising from stress in the populations concerned and public acceptability were the driving forces or major criteria in evaluating strategies for the future. Reductions in radiological effects were of secondary importance compared with public acceptance. The conferences achieved a considerable consensus on the structure of the decision model and on the general pattern of relocation and protection strategies to consider.

All decision conferences discussed and evaluated a range of strategies for implementing relocation and other protective measures. All people receiving projected doses in excess of an upper level would be relocated. Those receiving projected doses between an upper level and a lower level would be subject to protective measures other than relocation and might also receive some compensation. All those receiving doses below the lower level would not be subject to any protective measures.

Long term countermeasures proposed (for example, 'relocation' or 'safe living', which is understood as the whole spectrum of actions envisaged in the three Republics for the non-relocated population, including the provision of clean food) ranged in cost per unit collective dose averted from 300 000 to over 1 000 000 roubles ($200 000–$700 000) per man-sievert. This range may be compared with values used in western Europe for radiological protection decisions related to the introduction or modification of practices of $10 000–$20 000 per man-sievert.

The lifetime doses for the period 1990–2060 are expected to total about 50 000 man·Sv in the three Republics. In the decision processes in the Republics, therefore, it was apparent that the reduction of objective health effects was of less overall importance than matters having to do with public acceptance. The considerable expenditures allocated to future countermeasures seemed disproportionate to the effective radiological protection achieved by relocation.

Socioeconomic and political issues have thus become the most important factors in the official decision process. It should be recognized that ignoring the cost-benefit ratio of severe countermeasures such as relocation is inappropriate. If the population believe that countermeasures are introduced with the prime purpose of protecting them against health effects, they will press decision makers to reduce intervention levels even further. The decision makers, striving for broad public acceptance of their decisions to calm popular unrest, may reduce the levels even when they are aware that this will not effect any significant improvement in the health conditions and may cause the misallocation of scarce resources in the name of radiological protection.

It is, therefore, of great importance that decision makers inform the population of all aspects of their decisions, especially when the intervention levels chosen are based mainly on socioeconomic or political, rather than radiological protection, objectives. Otherwise, the population will be misled and the radiological protection community will be mistrusted.

General Conclusions

The unprecedented nature and scale of the Chernobyl accident obliged the responsible authorities to respond to a situation that had not been planned for and was not expected. Thus, many early actions had to be improvised. The Project teams were not able to investigate in detail many actions taken by the authorities owing to the complexity of the events. In those cases in which the Project teams were able to assess these actions, it was found that the general response of the authorities had been broadly reasonable and consistent with internationally established guidelines prevailing at the time of the accident. Some measures could doubtless have been better or taken in a more timely manner, but these need to be viewed in the context of the overall response.

The protective measures taken or planned for the longer term, albeit well intentioned, generally exceed what would have been strictly necessary from a radiological protection viewpoint. The relocation and foodstuff restrictions should have been less extensive. These measures are not justified on radiological protection grounds; however, any relaxation of the current policy would almost certainly be counterproductive in view of the present high levels of stress and anxiety amongst inhabitants of the contaminated areas of concern and people's present expectations. It is recognized, however, that there are many social and political factors to be taken into consideration, and the final decision must rest with the responsible authorities. At any rate, no modification introduced should lead to more restrictive criteria.

Detailed Conclusions

EVACUATION AND THYROID BLOCKING

The intervention levels of dose for evacuation established by the authorities were consistent with international guidance at the time of the accident.

The general policy for administration of stable iodine established by the authorities was in compliance with the international guidance at the time of the accident. The numerical values of the intervention levels, however, were not in full agreement with those recommended internationally.

The resources required to evaluate the practical implementation of these two protective measures were far in excess of those available within the Project. Consequently, only a superficial analysis was made of these aspects, on which no further conclusions can be made.

SURFACE DECONTAMINATION

Efforts were made after the Chernobyl accident over a period of several months to reduce external exposure due to radioactive materials that were released in the accident and deposited on surfaces. The wide range of measures taken included: the removal of soil to a depth of 10–15 cm; asphalting and covering soil with gravel, broken stones, sand or clean soil; daily mechanized washing; surface washing; demolition of structures; and burial of waste. These measures are reported to have been moderately effective; however, the Project teams did not specifically investigate these reports.

FOOD RESTRICTIONS

Criteria

The basis on which the intervention levels for food restrictions established by the authorities were derived was broadly consistent with international guidance prevailing at the time of the accident. There was, however, considerable ambiguity in the international guidance. Furthermore, the derived levels of radionuclide concentrations for various foodstuffs established by the authorities were based on consideration of the most exposed persons, i.e. the critical group, as opposed to the average individual in the affected group.

With allowance made for the differences in formulation between the respective criteria, the intervention levels established by the authorities are at the lower bound of the range recommended internationally. In view of the scale of the accident, the extent over which restrictions were needed and the shortcomings in food supply and distribution in the areas concerned, higher values of intervention levels would have been justifiable.

Impact

Doses actually received due to the ingestion of contaminated foodstuffs were substantially lower than the prescribed intervention levels of dose, typically by a factor of 2–4, and as a consequence foodstuffs may have been restricted unnecessarily.

The social consequences, including costs, of banning the consumption of foodstuffs were in many cases disproportionate to the doses averted.

Relaxation of the criteria for foodstuffs should be considered as a preferable alternative to relocation when overall health, social and economic effects are taken into account. Continuing restrictions on the consumption of domestically produced food in the contaminated areas of concern imply for some people a serious deterioration in the quality of life which may only be remedied by relocation to areas where previous lifestyles can be resumed. The relatively low intervention levels adopted for foodstuff restrictions may have exacerbated these problems.

An immense and largely successful effort has been made by the authorities to contain the agricultural consequences of the Chernobyl accident. Great efforts have also been made to reduce radiation risks to the population as a whole and to agricultural workers and their families in particular. The negative social effects of agricultural countermeasures could be further reduced by employing certain types of caesium binder.

RELOCATION

Criteria

The bases on which the criteria for relocation were derived by the authorities are not wholly consistent with the principles currently recommended internationally; this, however, does not necessarily imply that the quantitative criteria adopted are inappropriate.

In establishing relocation criteria, there were various conceptual misunderstandings and terminological problems among the parties concerned (including central and local authorities) that contributed to many of the present problems:

- The use of imprecise terminology and the misunderstanding and/or misrepresentation of some fundamental radiological protection concepts and principles, on the part of both the scientific community and others, have been a source of much needless confusion and disagreement in the USSR. This, taken together with the considerable delays in developing policy and effectively communicating it, has been largely responsible for the failure to reach a broad consensus on relocation policy. Moreover, it has contributed to a loss of confidence on the part of the affected population in the measures being taken in their interest.
- One of the more important misunderstandings or misrepresentations has been confusion over, and lack of recognition of, the very different origins and purposes of the dose limits recommended internationally for controlling planned

> increases in radiation exposure and those of the dose levels at which intervention is prompted to reduce existing radiation exposures. Dose limits per se are not the appropriate levels at which to intervene following an accident. The dose averted by relocation is the relevant quantity for judging the radiological benefits of relocation and, where practicable, quantitative criteria should be expressed in terms of this quantity.

It is not evident that considerations of averted dose were at the origin of all the criteria that have been proposed by the authorities. Criteria may also be formulated in terms of other, more useful derived quantities that are surrogates for averted dose (for example, contamination level, annual dose, lifetime dose or dose rate). A number of these have been used in the USSR, each having merits and disadvantages. In particular, surface contamination is not generally applicable for dose estimates because there is a strong dependence of dose estimates on local soil conditions, food consumption habits and lifestyle.

Social Impact

It appears that due account has not been taken by the authorities of the many negative aspects of relocation in formulating the relocation policy. There are indications from studies in other areas that the mass relocation of people leads to a reduction in average life expectancy (through increased stress and changes of lifestyle) and a reduced quality of life in a new habitat.

In applying a lifetime dose criterion for relocation, it is inappropriate to take account of past doses. Intervention may reduce the risk of adverse health effects in proportion to the dose averted but it can have no influence on doses already received before the intervention. For dose ranges below the threshold for deterministic effects, it is conceptually unsound and in contradiction to the principles for intervention to take past doses into account. There are, however, circumstances in which the total, past and projected, doses received may be the relevant quantity, for example in judging the need for and extent of any long term medical follow-up or care of those exposed as a result of the accident.

The cautious approach adopted (i.e. overestimates) in the estimation of doses to people living in the contaminated areas of concern, on the grounds that this was in their best interest, was inappropriate in principle and contradictory to the fundamental objectives of intervention. It had two important negative consequences: firstly, the radiological consequences of continuing to live in contaminated areas were overstated and this contributed to additional and unnecessary fear and anxiety in the population; secondly, and more importantly, some people will be relocated needlessly.

The average levels of individual lifetime dose that could potentially be averted by relocation, prompted by either the 350 mSv (35 rem) or the 40 Ci/km^2 (1480 kBq/m^2) criterion, are of the same order as or less than the doses due to average natural background radiation.

It is not clear that the modest nature of the doses that could be averted by relocation, and their assumed risks, are fully appreciated by either the population of the contaminated areas of concern or many of those people advocating a more stringent regime. The extra incremental risk to which an individual remaining in a contaminated area would be exposed would be marginal in comparison with risks experienced in everyday life and in itself would not justify such a radical measure as relocation.

Policy Reappraisal

On strictly radiological protection grounds, there can be little if any justification for the adoption of more restrictive relocation criteria than those currently adopted in the All-Union programme (i.e. 40 Ci/km^2, or 1480 kBq/m^2). Indeed, a reasonable case could be made for a relaxation in the policy, i.e. for an increase of the intervention levels.

A much larger number of people than those living in settlements with contamination levels in excess of 40 Ci/km^2 (1480 kBq/m^2) are to be relocated; the doses averted by the relocation of these people will be significantly less than the modest values already indicated. The implications of this are that more restrictive criteria are being adopted in practice.

Many factors, other than those of a strictly radiological protection nature, have had an important and possibly overriding influence on relocation policy. The need to restore public confidence, which has been seriously eroded for many reasons over the past five years, to reduce anxiety and to gain broad acceptance for the policy was identified to be particularly important. In ongoing reappraisals by the authorities of the relocation policy, these factors are being assigned much greater weight than factors of a strictly radiological protection nature. The relative importance to be attached to the various factors is, however, a matter for the relevant authorities.

Future changes in relocation policy will inevitably be constrained by past actions. Notwithstanding the merits of and technical justification for a change in policy, acceptance of major changes would be difficult to achieve, particularly where these involved a relaxation in the criterion previously adopted. A relaxation in the current relocation policy (i.e. a higher intervention level) would, however, almost certainly be counterproductive given the very difficult social conditions in the contaminated areas of concern. There can be no justification on radiological protection grounds for the adoption of a more restrictive policy. This should be strongly resisted unless there are overriding considerations of a social nature.

Recommendations

PROTECTIVE MEASURES

Arrangements should be made in the future for the compilation of a comprehensive and agreed database containing all relevant information on the implementation and the efficacy of the protective measures taken and this should be processed into a coherent framework.

A complete and detailed evaluation should be made of the protective measures taken (or planned to be taken) in order to validate the conclusions of the Project study. This should cover all aspects related to radiological protection, i.e. the doses, the costs and the efficacy of the protective measures.

Agricultural measures that may have a less adverse impact on traditional agricultural practices should be investigated.

PUBLIC INFORMATION

Factors that may influence the acceptability to the local population of continued habitation of settlements in the contaminated areas of concern should be further identified and analysed.

More realistic and comprehensive information should be provided to the public on the levels of dose and risk consequent upon their remaining in the contaminated areas of concern. These risks should be compared with risks experienced in everyday life and with risks from other environmental contaminants, e.g. radon and industrial emissions.

RESOURCE ALLOCATION

A comparison should be made between the effectiveness of resources allocated to the mitigation of the consequences of the accident and those allocated elsewhere to other programmes for public health improvement.

An assessment should be undertaken of the cost and effectiveness of relocation for a number of individual settlements, chosen to encompass the range of different characteristics encountered, in order to confirm the validity of the conclusions reached for average settlements.

Appendix

Historical Portrayal

Sources for this appendix include published material on the Chernobyl accident and the interviews conducted by Project experts with people living in the affected areas as well as with governmental officials and scientists. This portrayal is in no way intended to imply judgements based on hindsight or to detract from the courage of those who acted to save the lives of others, or to criticize those who made difficult decisions on the basis of limited information.

Emergency Actions at the Site

In the early hours of Saturday 26 April 1986, an accident which was to have global repercussions occurred at Unit 4 of the Chernobyl nuclear power plant in the UkrSSR. Seconds past 01:23 Moscow time, two explosions in quick succession blew the roof off the Unit 4 reactor building. Concrete, graphite and debris escaped through a hole which exposed the reactor core. Smoke and fumes along with a large amount of radioactive material rose in a hot plume almost 2 km high to be carried throughout the western portions of the USSR, to eastern and western Europe, and — in much smaller amounts — through the Northern Hemisphere. Heavier debris and particles fell near the site while lighter particles were carried west and north of the plant to the surrounding areas and neighbouring Soviet Republics.

Fires broke out on the roof of the adjoining turbine building. Fire, along with clouds of steam and dust, filled the Unit 4 building. Alarms went out to fire units in the region and within minutes plant firemen arrived. None of the firemen had been trained in fighting fires involving radioactive materials. Some set to work with plant personnel in the turbine hall and the Unit 4 building while others climbed to the roof of Unit 3, where they had to deal with burning graphite from the exploded core. By dawn on Saturday all but the graphite fire in the core had been extinguished.

An explosion of this nature had not been considered possible by many Soviet nuclear experts and the initial reports of core destruction by workers who entered the Unit 4 building were not believed. Operators continued to direct water into the reactor building in a vain attempt to cool the reactor core and this contaminated water flowed to building levels that crossed to other units, causing later contamination problems.

Rescue workers, firemen and operating personnel were generally unaware of the seriousness of the radiation risk. The high radiation levels could not be measured with available monitoring equipment and in some areas must have exceeded 100 Gy/h. Personnel had no dosimeters to measure their radiation dose and many were seriously irradiated. Less than an hour into the emergency the first case of acute radiation syndrome was evident. The number of persons present at the reactor site in the early hours of 26 April who showed clinical effects due to radiation exposure or burns was 203.

Signals indicating a serious accident involving an explosion, fire and radiation from Chernobyl were transmitted automatically to the State Committee on the Utilization of Atomic Energy in Moscow moments after the accident. As the information accumulated, even though the magnitude of the accident had not yet been fully established, it was decided to send key people from Moscow to direct operations. Top officials were called together as a Governmental Commission to provide the authority to mobilize resources. The plant management did not have the resources or authority to manage the response to an accident of this scale and it was the Governmental Commission itself that directed operations. Unit 3 was shut down around 03:00, an hour and a half after the accident, while Units 1 and 2 were not shut down until the following night, about 24 hours later.

Army forces were asked to carry out the first radiological assessment and to assist in controlling the fires. Early measurements showed neutron emissions, indicating continuing nuclear reactions in the destroyed Unit 4 core. As the accident would be more devastating if it spread to the other units, the Governmental Commission gave first priority to graphite fires.

The plant emergency plan was not suitable for an accident with large and continuous releases of radioactive material. Emergency facilities and emergency equipment were insufficient. There were no individual dosimeters for the emergency response units and no automatic radiation monitoring stations in the environs. Civil defence authorities specified possible shelters and proposed that the Pripyat town executive committee inform the population by radio of the radiation danger, but this was only done on Sunday just before the evacuation.

High radiation levels forced the Governmental Commission to move its headquarters from the town of Pripyat, 3 km from the reactor, to the town of Chernobyl, 15 km south-southeast of the plant, on 4 May. There were now thousands of people working on the site and the organizational responsibility to provide them with equipment and food was transferred to the Deputy President of the Council of Ministers of the USSR, who set up an operations management centre.

With the destroyed core open to the atmosphere, it was decided to cover the crater with heat absorbent and filtering materials. Airforce pilots flew hundreds of hazardous missions over the core, from 27 April to 10 May, in helicopters rigged to drop tonnes of boron, lead, clay, sand and dolomite.[6] A growing concern was the possibility that molten fuel would reach the water in the pressure suppression pools below the core, causing steam explosion and further releases. Under extremely difficult conditions and in a radioactive environment, military volunteers managed to rig up temporary piping to pump out water that had filled the normally dry second level. The command team also undertook the installation of a concrete slab underneath the damaged reactor to prevent any molten fuel from damaging the floor structure and leaking into the ground below.

Evacuation of the Prohibited Zone

EVACUATING PRIPYAT

Early on Saturday 26 April the explosion and fire at the plant were reported to BSSR and UkrSSR and district civil defence authorities. Within hours, a UkrSSR headquarters had been set up in Pripyat and police established roadblocks to prevent all but emergency vehicles from entering. By noon, regular radiation monitoring had begun in and around Pripyat. The highest readings were found just to the west of the plant, but the wind was light, slowing the spread of radioactive material. Civil defence officials prepared for Pripyat's evacuation although only the USSR Government had the authority to initiate it.

By the evening, radiation levels were up to 1000 times natural background radiation (0.1 mSv/h) in Pripyat. Although the radiological situation was not yet considered alarming, the physicists on the Governmental Commission were recommending evacuation as they were uncertain about the condition of the reactor core and the future course of the accident. The Commission decided at about 22:00 to evacuate the population on the next day, 27 April. They contacted transport officials from as far away as Kiev and arranged for more than a thousand buses, which arrived throughout the night. Officials in the nearby towns of Polesskoe and Ivankov were alerted to prepare for receiving the evacuees.

[6] The materials were chosen for specific purposes: boron to absorb neutrons and to prevent the reactor from becoming critical again; lead to absorb heat and act as shielding; clay and sand to filter out radioactive particles; and dolomite to give off carbon oxide to reduce the flow of oxygen to the graphite fire.

Evacuation routes were chosen in accordance with area radiation measurements and precise instructions for leaders, drivers, police and evacuees were prepared.

Meanwhile, because of the obvious severity of the accident — the explosion had been heard, smoke and fire were visible, civil defence forces were monitoring the city, injured were arriving at the hospital and plant workers had alerted their families and others — some officials took action on their own initiative. They warned others to stay indoors and distributed available potassium iodide tablets. Some teachers, recalling earlier civil defence training, cancelled Saturday outdoor events. They kept students indoors and attempted to prevent contaminated outdoor air from entering the buildings. Other people decided to leave Pripyat by train or river boat before the service would be cut off, and those who could left by car before roadblocks would be in place.

Officially, life in Pripyat was allowed to proceed more or less normally on Saturday. Steps were taken to prevent panic. Civil defence officials did not use face masks until after the evacuation as there had not been enough to supply the children. An amusement park which had been brought back into use only a few days before was open, with many people present. There were no official warnings or instructions to stay indoors and no systematic distribution of potassium iodide tablets.

At 07:00 on Sunday morning, 27 April, the head of the Governmental Commission confirmed the decision to evacuate Pripyat. He met with Pripyat town officials at 10:00 and instructed them to prepare for evacuation at 14:00. Around noon, a short official announcement was broadcast to city residents to pack provisions for three days and to be ready to leave at 14:00. The nearly 1200 buses assembled near the town of Chernobyl were set in motion in a line several kilometres long and the evacuation of Pripyat began at 14:00, just over 36 hours after the accident.

The number of people to be transported was less than the projected 44 600 as some had already left or were away for the weekend. There was adequate transport and the evacuation went smoothly. In less than three hours the city was emptied of all but those with official duties. The evacuees were taken in by individual families in towns or villages in the surrounding regions.

EXPANDING THE EVACUATION ZONE

On 28 April, the civil defence authorities of the UkrSSR and the USSR proposed the establishment of a 10 km exclusion zone around the plant. On 2 May, high governmental officials arrived from Moscow. Prime Minister Ryzhkov, who could call upon the industrial resources of the USSR, created an operational group of the Politburo Central Committee to direct the national effort. Fundamental decisions could now be taken regarding necessary work as well as the contributions and participation required from organizations throughout the USSR.

On 2 May it was decided to evacuate people from a zone of 30 km radius around the reactor; this zone became known as the prohibited zone. The evacuation of the entire prohibited zone was completed on 6 May. It was an undertaking requiring transport of thousands of people and thousands of farm animals. The zone was fenced off and access has been controlled ever since. While the area still remains evacuated, numerous people enter and leave to work at the site and in cleanup and research activities in the town of Chernobyl. A substantial number of people who left their homes later returned surreptitiously and some families have reportedly been allowed to return in less contaminated southern areas of the zone. In addition to the 30 km prohibited zone, evacuations were carried out from territories east and west of the zone where radiation levels exceeded 50 μSv/h (5 mrem/h). On 10 May a dose rate map was drawn with isopleths: a rate of 200 μSv/h (20 mrem/h) formed the boundary of the prohibited zone (about 1100 km^2 in area), 50 μSv/h (5 mrem/h) the boundary of the evacuation zone (3000 km^2) and 30 μSv/h (3 mrem/h) that of the strict controlled zone (8000 km^2), from which children and pregnant women had to be temporarily evacuated. The maps of contamination by long lived isotopes prepared in June and July 1986 showed that resettlement had to be carried out from an additional 29 settlements in the BSSR and 4 in the RSFSR.

Securing the Site

It was necessary to isolate the destroyed and contaminated reactor building. Engineers decided on a structural covering with a span of 55 m that used remaining walls as supports. Design work and construction proceeded quickly, allowing Unit 4 to be enclosed inside a concrete and steel shell by mid-November 1986. In order to monitor conditions inside the structure, both gamma radiation and temperatures are measured in various locations. Approximately 96 per cent of the fuel remains in the reactor and the premises of Unit 4. A steadily decreasing gamma dose rate indicates that the fuel is in a stable condition.

Because of the difficult conditions under which it was built, as well as the need to ventilate it, the 'sarcophagus' was not sealed from the environment. Spaces exist between construction elements in the upper part of the structure and there are holes in the roof to provide natural convection inside. The spaces are monitored for radioactive emissions.

Radiation Release and Transport

It is estimated that 25 to 50 million curies of radioactive elements were released from the reactor core. The intense heat increased the release of the volatile isotopes of iodine and caesium. There were approximately ten million curies of iodine released and approximately two million curies of caesium. The releases did not occur in a single large event. In the five days that followed the initial release, the release rate declined, reaching a minimum of approximately 15 per cent of the initial release rate. During the following four days the release rate increased to about 70 per cent of the initial rate. A sudden drop to less than 1 per cent of the initial rate then occurred, with a continuing decline thereafter.

During the first day, the plume above the plant reached 1800 m. By the following day, the maximum height was 1200 m, with the bulk of the material being released not exceeding 600 m. From the third day onward, the plume did not exceed 600 m.[7] At the time of the accident, surface winds were light and variable, but at 1500 m altitude the winds were 8–10 m/s from the southeast. Material carried to this height was transported towards Finland and to Sweden, where radioactivity was first detected outside the USSR on 27 April. Moscow TV broadcast news of the accident on the evening of Monday 28 April.

By 7 May, maps of radiation levels over the European territory of the USSR were completed on the basis of data collected by aerial surveys. From then on, the USSR Hydrometeorology Institute released data on a daily basis with forecasts of transfer trajectories at various altitudes which were transmitted to local authorities and to the Ministries of Health and Agriculture.

Protection of Rivers and the Kiev Reservoir

One of the more critical issues was the potential for contamination of the water system and from the first days after the accident, studies of water contamination were begun by the State Committee on Hydrometeorology. Monitoring of radionuclide concentrations in the area of the River Dnepr and its tributary the Pripyat indicated that contamination was principally from fallout

[7] The volatile elements iodine and caesium were detected at even greater altitudes (6–9 km), with traces also in the lower stratosphere. The heavier elements, such as cerium, zirconium, neptunium and strontium, were of significance only in local deposition within the USSR.

since there was a sharp reduction in radionuclide concentration as the airborne contamination decreased.

In the very first days after the accident, estimates were made of the concentrations of radioactive contamination in water bodies due to the fallout and of projected concentrations if rainfall were to bring additional radioactive contaminants from the ground into the water system. Calculations showed that in the event of intensive rainfall in the vicinity of the River Pripyat, the concentration of the most critical radioactive isotope ^{90}Sr would not exceed the limits set for drinking water by the USSR regulations, provided releases from the reactor would soon be terminated. Later measurements confirmed this forecast.

Owing to the heavy fallout in the immediate vicinity of the reactor, the nature of the soils in the area and the direct connection through the nearby cooling pond to Kiev's principal reservoir on the River Dnepr north of Kiev, a good deal of effort was made to slow the movement of long lived radionuclides (such as ^{137}Cs and ^{90}Sr) through ground or surface water. There were three major undertakings. First, 140 dams and dikes were built to limit runoff from the site area into the cooling pond and the adjacent River Pripyat. Second, a series of existing silt traps at the bottom of the rivers, the pond and the reservoir were scoured. Third, an 8 km long barrier, 30–35 m deep, was built around the plant down to the impermeable clay layer to prevent the flow of radioactive water towards the River Dnepr.

Decontamination

After the major releases from the plant had subsided, decontamination was undertaken to reduce dose rates in areas from which the population had not been moved. Primary attention was given to municipal buildings such as schools, nurseries and hospitals while contaminated buildings of lesser importance were demolished and the waste buried.

At first, officials declared that much of the evacuated territory could be reoccupied after decontamination. However, in many cases decontaminated surfaces quickly became recontaminated owing to resuspension of radionuclides migrating from land, vegetation and structural surfaces. The most effective decontamination proved to be natural processes ('biological decontamination') such as decay and migration into the ground, and active decontamination work in most settlements has been discontinued.

Intervention Measures

After the initial evacuations, the USSR National Commission on Radiological Protection formulated intervention criteria for reducing exposure due to contaminated food and water. The main sources of exposure changed with time, as did the measures taken to control them. In the first few months, exposure was due to radioiodine in milk from cows that had grazed on contaminated pastures and this was dealt with through intervention measures such as the provision of potassium iodide and the supply of clean milk. At the same time, the problem of radioiodine and other nuclides deposited on fresh vegetables was addressed through intervention measures such as the supply of clean food. Over the long term, the principal exposure was due to ^{137}Cs in milk, meat and other foods and this was dealt with through intervention measures restricting food production and consumption, and changes in agricultural management.

ESTABLISHING THE SAFE LIVING CONCEPT

The radiation protection situation was complicated by the extent of the areas contaminated and the huge control programme necessary for measuring both environmental and food contamination. A number of safe living concepts have been proposed, including a temporary dose limit introduced during the first year, a lifetime dose limit concept, a two-tier lifetime dose limit concept, a dose rate concept and a surface contamination concept. The USSR Ministry of Health introduced a maximum temporary dose limit of 100 mSv (10 rem) for the first year after the accident. A set of additional temporary dose limits for the years 1987–1989 were later approved.

By early 1987, it became increasingly apparent that the food and behavioural restrictions were having a major impact on everyday life in the three Republics. Authorities recognized that the system of restrictions on farming in the predominantly rural, agricultural regions would not be satisfactory in the long term. In late 1988 they proposed a lifetime 'safe living concept' that was to define radiological conditions under which people were not subject to restrictions on their diet or lifestyle. This set the lifetime dose limit over 70 years from the time of the accident at 350 mSv (35 rem). The limit was an action/no-action level concept. The concept was approved by the Council of Ministers of the USSR in September 1988.

By the beginning of 1989, however, the lifetime dose limit concept was being seriously criticized. Proponents of the concept argued that lower values would result in severe disruption as a result of excessive relocation. As a result of mounting criticism it was expanded to a two-tier system. This modified version included a lower level of lifetime dose (70 mSv (7 rem)) below which no action was to be taken. Between the lower and the upper levels (still 350 mSv (35 rem)), varying measures would be introduced. Above the upper level, relocation remained compulsory.

In April 1990 the Supreme Soviet of the USSR introduced a surface contamination concept as a criterion for both relocation and payment of compensation. This divides the affected areas into three classes of zones[8]: those with a surface contamination level of caesium above 40 Ci/km^2 (1480 kBq/m^2); those with levels in the range 15–40 Ci/km^2 (555–1480 kBq/m^2); and those in the range 1–15 Ci/km^2 (37–555 kBq/m^2). Relocation and other forms of compensation would depend upon which zone a settlement was in.

The policies on protective measures and relocation were not understood by the general public and contributed to a distrust of both the scientific and political authorities. Growing reports of widespread health effects also had a particularly strong impact on the public. This situation was not helped by officials who began attributing public fears to 'radiophobia' or undue concern about radiation and its health effects. When the 'safe living concept' was announced in early 1989, it immediately became the target of criticism in the three affected Republics where many people, including scientists, disagreed with the permitted radiation exposure limits.

[8] This was done despite the fact that there is no simple relationship between the surface contamination level and annual dose or lifetime dose because of differences in transfer factors, living conditions and eating habits.

Soviet Requests for Assistance

The current situation in the USSR is reflected in a resolution "On the Political Evaluation of the Chernobyl Nuclear Power Station Disaster and Progress in Eliminating its Aftermath" which was adopted in July 1990 at the 28th Congress of the Communist Party of the Soviet Union:

> "...the CPSU Cèntral Committee Politburo, the USSR Council of Minister, the Central Committees of the Communist Parties of the Ukraine and Byelorussia, and the Councils of Ministers of the Ukraine and Byelorussia, failed to assess the scale of the disaster and its possible consequences promptly enough, or to work out and resolutely implement a government concept of safe residence in contaminated areas.

Social tensions in the afflicted areas are rising. This is prompted by the long and unjustified secrecy surrounding the Chernobyl tragedy, the conflicting evaluations, especially of the medical aspects, and the shortage of unbiased information made available to the population about the actual state of affairs.

The Congress admits that the measures taken to eliminate the aftermath of the Chernobyl disaster were unsatisfactory and insufficient.''

In 1989, during the period of ferment leading to the resolution of the Congress, international organizations were asked to help investigate the general health and welfare situation. The WHO sent a team of officials in 1989, as did the League of Red Cross and Red Crescent Societies in early 1990. It was in October of 1989 that the USSR Government made its request to the IAEA for assistance, resulting in the present study which was carried out under the International Advisory Committee.

Epilogue

The accident at Chernobyl had a societal impact unparalleled in industrial history. The early consequences resulted in the evacuation of more than 100 000 people and involved hundreds of thousands of rescue workers. Vast populations in the BSSR, the RSFSR and the UkrSSR continue to live with stress and anxiety due to the lingering uncertainty about the future. The International Chernobyl Project launched in 1990 was an important step in assisting the affected population. Additional initiatives are already under way to deal with the many consequences of the accident.

In response to Governmental appeals for assistance, the United Nations system has launched a number of activities. The General Assembly adopted, on 21 December 1990, resolution 45/190, which requests the Secretary General:

> " ... to support efforts made within the United Nations system by the Administrative Committee on Co-ordination and the Inter-Agency Committee for the Response to Nuclear Accidents to harmonize, strengthen and co-ordinate international projects dealing with mitigating the consequences of the disaster at Chernobyl ..."

The resolution urgently appealed:

> " ... to all States members of the international community, intergovernmental and non-governmental organizations, the business community, scientific bodies and individuals to continue to provide all appropriate support and assistance to the areas most affected by the accident at the Chernobyl nuclear power plant, in full co-ordination and co-operation with envisaged or planned efforts of the United Nations system."

The United Nations Secretary General has appointed the Director General of the United Nations Office in Vienna to co-ordinate assistance within the United Nations system. A task force is currently concentrating its efforts on the enormous economic and social consequences. The Inter-Agency Committee for the Response to Nuclear Accidents, formed shortly after the Chernobyl accident, is encouraging its United Nations system members to carry out research aimed at better understanding environmental contamination, agricultural measures, radiological protection and emergency management following a large release of radioactive material.

The World Health Organization is proceeding with plans for a long term international programme for the study of medical aspects of the Chernobyl accident and for the establishment in the USSR of a WHO international centre to study radiation medical problems.

The BSSR, the UkrSSR and the USSR recently established the Chernobyl Centre for International Research. The area around Chernobyl affords opportunities for scientific investigations into post-accident conditions. The IAEA will have a role in the development and co-ordination of research at the Centre as well as in the dissemination of the results.

International collaboration in the growing number of humanitarian and scientific efforts will be an essential ingredient in fully alleviating the consequences of the Chernobyl accident.

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