increase in cancer incidence due to radiation exposure. However, for particular population groups at specific periods of time after the accident, it was felt that some effects due to radiation exposure could be detected using scientific methods (e.g. an increased incidence of leukaemia among the recovery operation workers and of thyroid cancer in people who were children in 1986).

2. Scientific limitations

93. The interpretation and communication of radiation risk projections is fraught with difficulties, because it is not easy to communicate their intrinsic limitations adequately.

94. As discussed previously in the section on the attribution of effects to radiation exposure, because presently there are no biomarkers specific to radiation, it is not possible to state scientifically that radiation caused a particular cancer in an individual. This means that in terms of specific individuals, it is impossible to determine whether their cancers are due to the effects of radiation or to other causes or, moreover, whether they are due to the accident or background radiation. The situation with the ARS survivors of the accident is fundamentally different since each of them is known by name and ARS was diagnosed and attribution to radiation exposure was based on conclusive medical findings. However, projected numbers of stochastic effects in anonymous individuals could be misunderstood to be of a similar nature to actual identified cases.

95. An additional misunderstanding occurs regarding the nature of the evidence for stochastic effects from studies of exposed populations. For example, there is reasonable evidence that acute radiation exposure of a large population with doses above 0.1 Sv increases cancer incidence and mortality. So far, neither the most informative study of the survivors of the atomic bombings nor any other studies of adults have provided conclusive evidence for increased incidence of carcinogenic effects at much smaller doses [U3, annex A of U1].

96. Because of the absence of proper experimental evidence, the dependence of the frequency of adverse radiation effects on dose can be assessed only by means of biophysical models, among which, the LNT model has been used widely for radiation protection purposes [B48, U3]. However, others have been suggested, including superlinear and threshold ones, and even models assuming hormesis. It is important to understand the considerable statistical uncertainty associated with any projection based on modelling, which lends itself rather to estimations that are within an order of magnitude or even more.

97. The currently available epidemiological data do not provide any basis for assuming radiogenic morbidity and mortality with reasonable certainty in cohorts of the residents of the areas of the three republics and other countries in Europe who received total average doses of below 30 mSv over 20 years [A11, C1, C11, R4, T4]. Any increases would be below the limit of detection. At the same time, it cannot be ruled out that adequate data on the effects of low-dose human exposure will be obtained as further progress is made in understanding the radiobiology of man and other mammals, and using this knowledge to analyse the epidemiological data. This may provide in the future the scientific basis for evaluating the radiation health consequences of the Chernobyl accident among residents of areas with low radiation levels.

3. UNSCEAR statement

98. The Committee has decided not to use models to project absolute numbers of effects in populations exposed to low radiation doses from the Chernobyl accident, because of unacceptable uncertainties in the predictions. It should be stressed that the approach outlined in no way contradicts the application of the LNT model for the purposes of radiation protection, where a cautious approach is conventionally and consciously applied [F11, I37].

VII. GENERAL CONCLUSIONS

A. Health risks attributable to radiation

99. The observed health effects currently attributable to radiation exposure are as follows:

- 134 plant staff and emergency workers received high doses of radiation that resulted in acute radiation syndrome (ARS), many of whom also incurred skin injuries due to beta irradiation;
- The high radiation doses proved fatal for 28 of these people;
- While 19 ARS survivors have died up to 2006, their deaths have been for various reasons, and usually not associated with radiation exposure;
- Skin injuries and radiation-induced cataracts are major impacts for the ARS survivors;
- Other than this group of emergency workers, several hundred thousand people were involved in recovery operations, but to date, apart from indications of an increase in the incidence of leukaemia and cataracts among those who received higher doses, there is no evidence of health effects that can be attributed to radiation exposure;
- The contamination of milk with ^{131}I, for which prompt countermeasures were lacking, resulted in large doses to the thyroids of members of the general public; this led to a substantial fraction of the more

than 6,000 thyroid cancers observed to date among people who were children or adolescents at the time of the accident (by 2005, 15 cases had proved fatal);

- To date, there has been no persuasive evidence of any other health effect in the general population that can be attributed to radiation exposure.

100. From this annex based on 20 years of studies and from the previous UNSCEAR reports [U3, U7], it can be concluded that although those exposed to radioiodine as children or adolescents and the emergency and recovery operation workers who received high doses are at increased risk of radiation-induced effects, the vast majority of the population need not live in fear of serious health consequences from the Chernobyl accident. (This conclusion is consistent with that of the UNSCEAR 2000 Report [U3]). Most of the workers and members of the public were exposed to low level radiation comparable to or, at most, a few times higher than the annual natural background levels, and exposures will continue to decrease as the deposited radionuclides decay or are further dispersed in the environment. This is true for populations of the three countries most affected by the Chernobyl accident, Belarus, the Russian Federation and Ukraine, and all the more so, for populations of other European countries. Lives have been disrupted by the Chernobyl accident, but from the radiological point of view, generally positive prospects for the future health of most individuals involved should prevail.

B. Comparison of present annex with previous reports

101. This annex reviews the scientific information obtained since the UNSCEAR 2000 Report [U3] on the exposures and effects due to radiation from the Chernobyl accident. Although many more research data are now available, the major conclusions regarding the scale and nature of the health consequences are essentially consistent with the previous UNSCEAR reports [U3, U7].

102. The radioactive release has been re-evaluated, but the changes are academic and not relevant to the assessment of radiation dose, which is based on direct human and environmental measurements.

103. Dose estimates have been extended for an additional number of about 150,000 emergency and recovery operation workers. Based on direct human and environmental measurements made since 1988 and models that take into account the actual countermeasures, the estimates of the thyroid dose to the evacuees have been updated. The estimated thyroid and effective doses to the inhabitants of Belarus, the Russian Federation and Ukraine have been expanded from five million to about one hundred million people and the estimated thyroid and effective doses to about 500 million inhabitants of most other European countries have been updated.

104. With regard to the follow-up of the ARS survivors, there is significant new information in this annex. By 1998, 11 ARS survivors had died [U3]; since then another 8 have died up to 2006. The annex discusses the causes of death in the context of their radiation exposure.

105. For the larger number of emergency and recovery operation workers, there are indications of an increased incidence of leukaemia and cataracts among those who received higher doses, although further clarification of the epidemiological information is still needed. The information on cataracts indicates that the threshold for induction may be lower than previously thought. While there have been indications of an increase in the incidence of cardiovascular and cerebrovascular diseases among the recovery operation workers that correlate with the estimated doses, major concerns over the possible influence of confounding factors and potential study biases remain.

106. In the UNSCEAR 2000 Report [U3], fewer than 1,800 thyroid cancers had become evident among those aged under 18 at the time of the accident; this had increased to more than 6,000 by the year 2006. Several studies have now been conducted that provide rather consistent estimates of the radiation risk factors for thyroid cancer.

C. Comparison of observed late health effects with projections

107. Early assessments [B47, I43, R4] conducted in 1987 projected a considerable increase in thyroid cancer incidence due to radiation exposure in the three republics, particularly among children. To date, some 6,000 thyroid cancers have been seen among those in the three republics who were under 18 at the time of the accident, of which a substantial fraction is likely to have been due to radiation exposure.

108. Projections [C1] made in 1996 using dosimetric information on the emergency and recovery operation workers had indicated that there might be a detectable increase in the incidence of leukaemia among those who had received relatively high doses of radiation. There has been some evidence of a detectable increase among a group of Russian workers, although at present, it is far from conclusive.

109. Several groups [A11, B47, C1, C11, F10, I43, R4] have projected possible increases in solid cancer incidence for the general population. These assessments differ in the exact populations considered and the dosimetry and projection models used. However, for all the populations considered, the doses are relatively small, comparable with those from natural background radiation, and any increase was unlikely to be detected by epidemiological studies. Although it is now one decade after the minimum latent period for solid cancers, no increases in cancer incidence (other than of thyroid cancer) have been observed to date that can be attributed to irradiation from the accident.

110. The use of theoretical projections is fraught with difficulty. It is extremely difficult to communicate such

projections accurately and honestly to officials and the general public. Moreover, there is a limit to the epidemiological knowledge that can be used to attribute conclusively an increased incidence to radiation exposure. Therefore, any radiation risk projections in the low dose area should be considered as extremely uncertain, especially when the projection of numbers of cancer deaths is based on trivial individual exposures to large populations experienced over many years.

D. New knowledge from studies of the accident

111. Although there is general consensus on the scale and character of the health consequences due to radiation from the accident, studies of the world's worst nuclear accident have clearly produced a vast amount of useful scientific information. Most of this can be used to validate predictive capabilities and knowledge developed from research and experience before the accident. Other information is completely new and is helping to fill gaps in the current scientific knowledge base.

112. The accident has provided clear evidence that confirms pre-existing knowledge of the importance of ^{131}I in the pasture–cow–milk pathway, of the need to take prompt countermeasures, of the potential high doses to the thyroids, and of the anticipated increase in thyroid cancer incidence, particularly among those exposed during childhood or adolescence. Ongoing research is helping to refine this knowledge, particularly with respect to the patterns of thyroid cancer incidence for different doses, pathways, age groups, and levels of dietary iodine.

113. Similarly, for protracted irradiation due to the longer-lived radionuclides, the pre-existing understanding of the important pathways of exposure to humans has been validated by the experience obtained from the accident. Moreover, there has been a greater recognition of the importance of soil type in determining the transfer of radiocaesium to foodstuffs, a greater understanding of the radioecology in urban, semi-natural and forest environments, and considerable experience in the implementation of a whole range of countermeasures.

114. With regard to health effects, there have been dramatic improvements in the understanding of acute radiation effects and their treatment, and of the long-term sequelae of local radiation injuries due to irradiation of the skin and lens of the eye. With respect to the incidence of stochastic effects other than thyroid cancer, so far there have been few observations that have challenged pre-existing understanding derived from the studies of other exposed groups, such as the survivors of the atomic bombings in Japan and other studies of radiation exposed populations.

ACKNOWLEDGEMENTS

115. The Committee wishes to express its deep gratitude for the contributions made by the following individuals in supporting the lead author, M. Balonov, in preparing this annex: the late G.R. Howe, L. Anspaugh, A. Bouville, A. Guskova, V. Ivanov, J. Kenigsberg, I. Likhtarev, F. Mettler, R. Shore, G. Thomas, M. Tirmarche and L. Zablotska. In addition, the Committee would like to recognize the valuable contributions of V. Bebeshko, D. Belyi, M.O. Bernier, G. Bruk, V. Chumak, S. Davis, V. Drozdovitch, I. Galstyan, N. Gentner, V. Golikov, L. Kovgan, Yu. Kruk, J. Kurtinaitis, V. Minenko, K. Rahu, S. Shinkarev, A. Stengrevics, and I. Zvonova.