Chernobyl disaster

Jan Willem Storm van Leeuwen

Independent consultant
member of the Nuclear Consulting Group

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storm@ceedata.nl

Note
In this document the references are coded by Q-numbers (e.g. Q2). Each reference has a unique number in this coding system, which is consistently used throughout all base papers by the author. In the list at the back of the document the references are sorted by Q-number. The resulting sequence is not necessarily the same order in which the references appear in the text.

Contents

FIGURES

1 Accident

On 26 April 1986 reactor 4 (type RMBK, graphite-moderated water-cooled) of the nuclear power plant at Chernobyl (Ukraine) went out of control during a test of the cooling system and exploded. More steam and hydrogen explosions followed, the graphite moderator ignited and burned for ten days, dispersing large amounts of radioactive gases and particles into the environment. The reactor had not been encased by any kind of hard containment vessel. Likely a hard containment would not have survived the explosions, anyway.

The amount of released radioactivity is a controversial issue. Some sources state some 1.85 exabecquerel (EBq), other 185 EBq, according to [Yablovkov 2011] Q565. At issue concerning this disparity is the moment after the release at which the estimate is made: during the first months after the fission process has stopped, the radioactivity of the nuclear fuel falls by a factor of 100 to 1000, due to the decay of short-lived fission products,
A consequence of the rapid decay during ther first month is that the affected people during the first days and weeks could be exposed to a dose of radioactivity hundreds to thousand times the dose they would contract several months later during the same period of time.
Apart from the quantitative aspects of exposure to radionucledes, another factor should be taken into account, that is the composition of radionuclides people are exposed to. During the first days and weeks the short-lived radionuclides are dominating the radioactivity of the released matter, for example I-131. After a couple of months other, long-lived radionuclides are dominating the radioactive contamination, for dozens of years, for example Sr-90, Tc-99, Ru-106, I-129, Cs-137. Biological half-life may be relevant in case of exposure during a short period to short-lived radionuclides, but not with regard to chronic contamination by long-lived radionuclides.
People living in the contaminated areas are chronically exposed to a gamut of radionuclides, via inhalation of dust and via ingestion of contaminated drinking water and food grown on contaminated soil.

A description of the Chernobyl 4 reactor and details on the events leading to the accident can be found at [WNA-chern 2016] Q###. In this paper the World Nuclear Association (WNA) endorses the findings of the IAEA, UNSCEAR and WHO with regard to the health and environmental effects of the accident, but it does not mention studies from independent organizations with diverging findings, such as the International Physicians for the Prevention of Nuclear War (IPPNW), Nobel Peace Prize 1985. This issue is briefly addressed in the following sections. WNA also mentions the repopulation and resettlement of contaminated areas and the reclassifying of those areas. In 2011 Chernobyl was officially declared a tourist attraction.

Dispersion of cesium-137

UNSCEAR published in 2000 a map of the dispersion in Europe of cesium-137, an easily detectable fission product, after the explosion of Chernobyl, see Figure 1. The lightest yellow colour corresponds with a contamination level of 2 kBq/m² of Cs-137 or less, which is attributable to residual levels from artmospheric nuclear weapon testing fallout, according to UNSCEAR. The darkest coloured areas, contaminated with more than 3700 kBq/m² of Cs-137, must be considered inhabitable due to high radioactive contamination, not only by Cs-137, but inescapably also by other radionuclides, which are not mentioned.
The dispersion of the many other kinds of radionuclides released from the exploded reactor does not follow the same pattern as Cs-137, for reason of the widely different physical and chemical properties of the radionuclides. Important to note is that many radionuclides are not easily detectable, including a number of the dangerous actinides. Therefore a map of health hazards might be significantly different from the Cs-137 dispersion map.

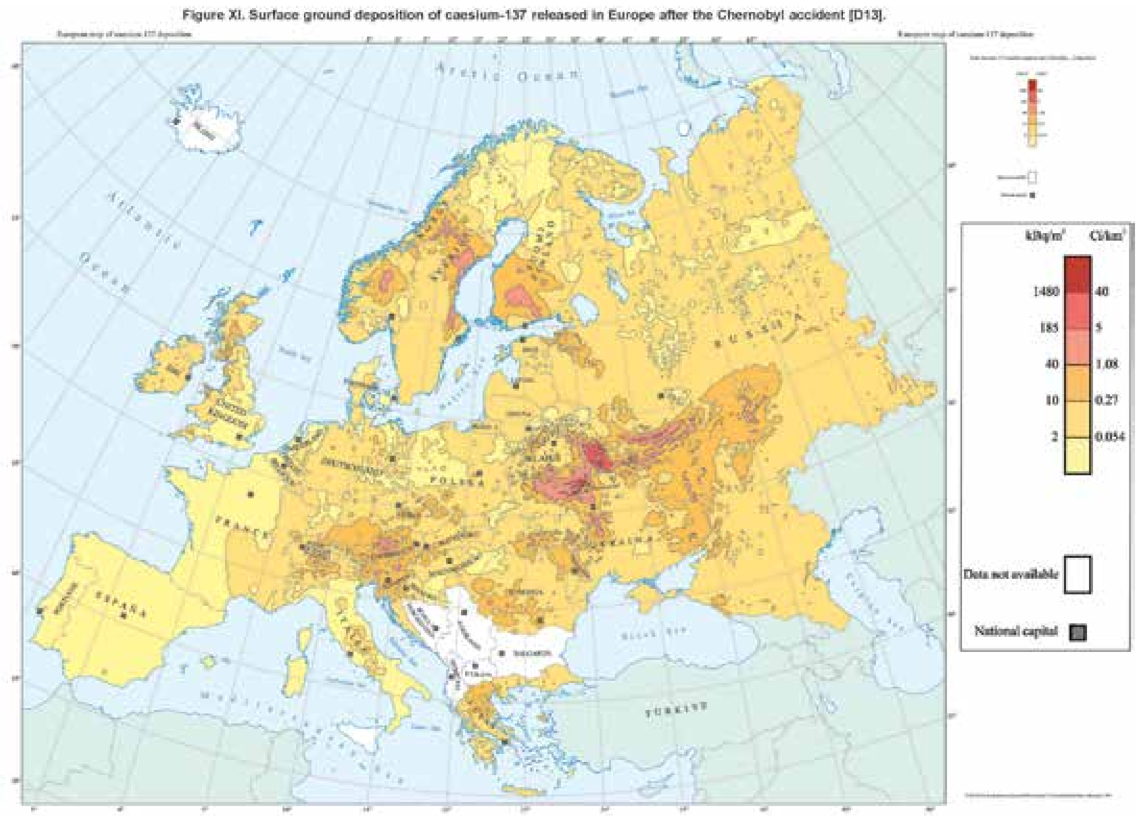

Figure 1
Surface ground deposition of cesium-137 released in Europe after the Chernobyl disaster in 1986. Sources: [UNSCEAR 2012] Q547], [UNSCEAR 2000] Q548]. The lightest yellow colour corresponds with a contamination level of 2 kBq/m² of Cs-137 or less, which is attributable to residual levels from artmospheric nuclear weapon testing fallout.

The spatial extent of the Chernobyl disaster is also illustrated by the dispersion of Cs-137 in Figure 2 which is based on meteorological models and the published amount of released Cs-137 , by another institute than UNSCEAR. The dispersion of other radionuclides estimated in a similar way seem to be not published or not known.

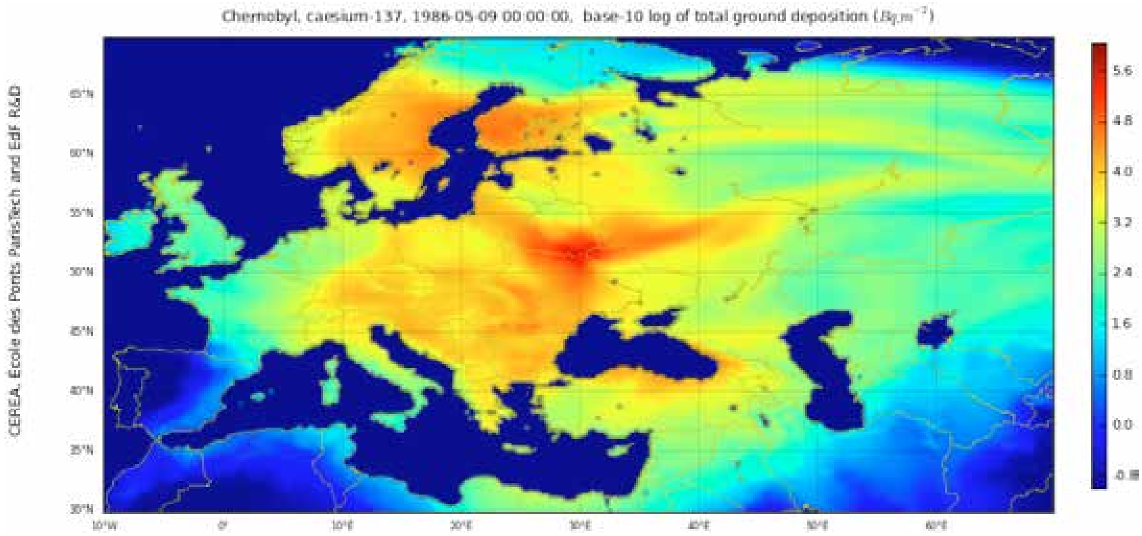

Figure 2

Map of the cumulative ground deposition of Cs-137 (Bq/m^2) on May 9, 1986 after the Chernobyl disaster. Note that the color scale at right gives the ^{10}log values of the surface activity; for example the number 4.8 on the scale corresponds with a surface activity of $10^{4.8}$ = 63 kBq/m^2. Souce: CEREA 2013 [Q505].

Definition of contaminated areas

The maps of Figures 1 and 3 indicate that areas with a deposition of Cs-137 at levels below 37000 Bq/m^2 are considered to be not contaminated. This observation is confirmed by the text of UNSCEAR 2000 [Q548]:

> "The contaminated areas, which are defined in this Annex as being those where the average ^{137}Cs ground deposition density exceeded 37 kBq m^{-2} (1 Ci km^{-2}), are found mainly ..."

A footnote in UNSCEAR 2008 [Q551] reads:

> "The "contaminated areas" were defined arbitrarily in the former Soviet Union as areas where the ^{137}Cs levels on soil were greater than 37 kBq/m^2."

These quotes raise the question on which scientific grounds UNSCEAR made the choice for the definition of 'contaminated areas'.
As pointed out above, these areas are contaminated by dozens of other radionuclides, likely in deposition patterns different from Cs-137 . Does the UNSCEAR definition of contaminated areas mean that the health hazards posed by other radionuclides are ignored?

Chemical compounds of cesium are a very soluble in water. From the maps in Figures 3 and 4 may follow that the water of the river Pripyat must be heavily contaminated by large amounts of Cs-137 and many other radionuclides during prolonged periods, and consequently the water of the lake 'Kiev Reservoir'.

Only a few maps have been published [UNSCEAR 2000] Q548 of the dispersion of radionuclides other than ^{137}Cs, namely strontium-90, plutonium-239 + 240, and iodine-131, see Figures below.

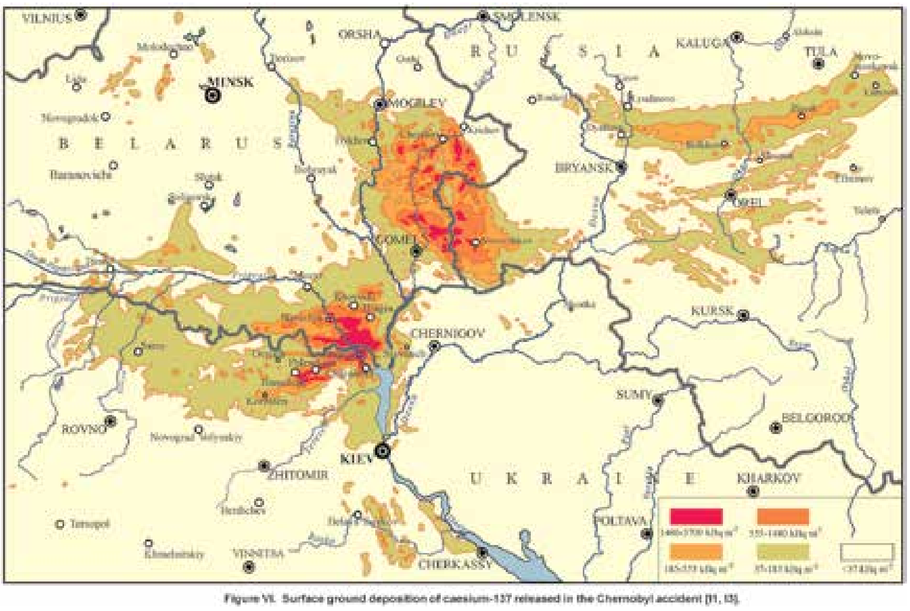

Figure 3

Surface ground deposition of cesium-137 released in the Chernobyl accident. Source: [UNSCEAR 2012] Q547, [UNSCEAR 2000] Q548.

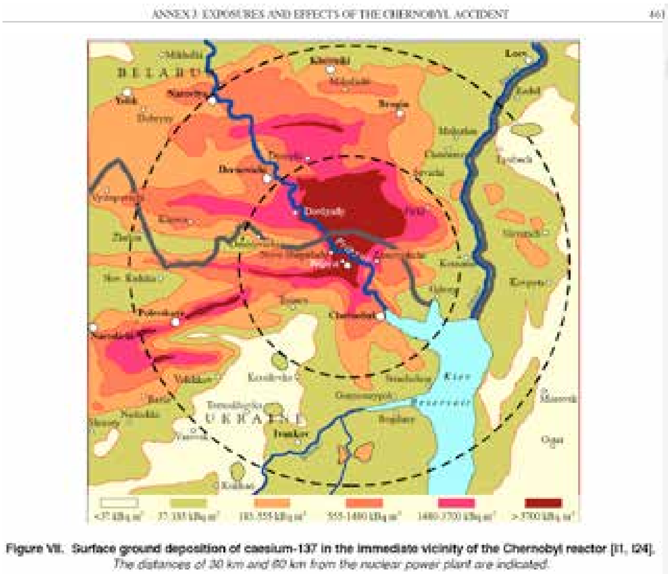

Figure 4

Map of ground deposition of cesium-137 in the immediate vicinity of the Chernobyl reactor. The distances of 30 km and 60 km from the nuclear power plant are indicated. Source: [UNSCEAR 2000] Q548.

Dispersion of strontium-90

The white areas in the map of Figure 5 are not free of Sr-90, but have a contamination level of less than 37000 Bq/m². Does this map suggest that Sr-90 contamination levels below 37000 Bq/m² are not harmful and therefore need not to be mapped? Apparently above definition of contaminated areas applies also to Sr-90 contamination.

Obviously the water of the Kiev Reservoir has been also contaminated with Sr-90.

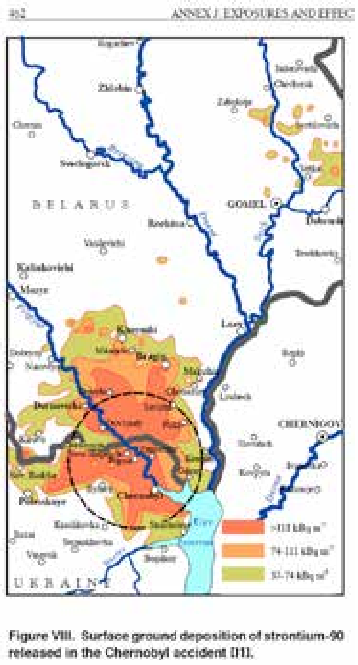

Figure 5

Map of suface ground deposition of strontium-90. another major fission product, released in the Chernobyl accident. The white areas in this map are not free of Sr-90, but have a contamination level of less than 37 kBq/m². Source: [UNSCEAR 2000] Q548. From this map may follow that the lake Kiev Reservoir must be heavily contaminated by Sr-90, not only by direct deposition but also thereafter, by the rivers flowing through the contaminated area around the Chernobyl reactor.

Dispersion of plutonium

From Figures 5 and 6 seems to follow that areas contaminated by less than 3.7 kBq/m² of Pu-239 + Pu-240 are considered as being not contaminated with these extremely hazardous radionuclides. No scientific argument are found in the open literature for this distinction.

If an area is contaminated by Pu-239 + Pu-240 it is also contaminated by Pu-238 and Pu-241, because the physical and chemical properties of the Pu isotopes are identical. Consequently the total radioactivity as a result of Pu contamination is considerably higher than indicated in the maps based on the two isotopes Pu-239 + Pu-240. Moreover, the half-lifes of the not-named isotopes are much shorter, so their specific radioactivity is much higher than of Pu-239 + Pu-240.

isotope	halflife (years)
Pu-238	87.8
Pu-239	24390
Pu-240	6540
Pu-241	15

Moreover the decay daughters of Pu-238 and Pu-241, U-234 respectively Am-241, are highly radiotoxic by themselves.

Dispersion of neptunium

Plutonium and neptunium are actinides formed from uranium by absorption of neutrons released by fission of fissile nuclei in the reactor core. Plutonium-239 is formed from uranium-238 via neptunium-239 by neutron capture and beta emission. In addition to the short-lived neptunium isotope Np-239 (halflife 2.35 days) sizeable quantities of the long-lived isotope Np-237 (halflife 2.14 million years) are formed, mainly by

neutron capture of U-235 and decay of americium-241.
In spent fuel the chemically reactive Np and Pu radionuclides are present as oxides, comparable with uranium oxide, and are non-volatile. During the Chernobyl accident large amounts of neptunium and plutonium have been blown into the air as aerosols from the burning graphite moderator, exacerbated by hydrogen explosions and steam eruptions.

Strikingly the reports of IAEA, UNSCEAR and WHO do not mention the dispersion of neptunium, despite its dangerous properties. From the maps of Datapoke (see report *Fukushima disaster* Figures 4, 5 and 6) follows that the aerosols with all isotopes of plutonium and neptunium can be dispersed over intercontinental distances. Likely vast areas in Ukraine, Belarus and Russia have suffered from a large deposition of neptunium. The short-lived isotope ^{239}Np has been decayed to ^{239}Pu in a matter of weeks. The long-lived isotope ^{237}Np stays in the soil after deposition and decays slowly to hazardous decay products. Actinides like plutonium and neptunium are bone seekers after ingestion: they tend to accumulate in the bone marrow. Their alpha radiation is extremely damaging in living tissue.

Figure IX. Surface ground deposition of plutonium-239 and plutonium-240 released in the Chernobyl accident at levels exceeding 3.7 kBq m^{-2} [I1].

Figure 6
Map of surface ground deposition of plutonium-239 + plutonium-240 released in the Chernobyl accident at levels exceeding 3700 Bq/m^2. The distance of 30 km from the nuclear power plant is indicated. Source: UNSCEAR 2000 [Q548].

Dispersion of radio-iodine

The map in Figure 7 represents the disperaion of iodine-131. Remarks:

- The white areas in the map of Figure 7 are areas with a surface ground deposition of 37-185 kBq/m^2 of ^{131}I. The white colour suggest that these areas are considered to be not contaminated according to the definition of UNSCEAR, but probably the lower limit of ‘contaminated area’ for ^{131}I is also 37 kBq/m^2, as for ^{137}Cs and ^{90}Sr.

- Strikingly no estimates have been published of the ^{131}I deposition in Ukraine, for unexplained reasons.
- The ^{131}I deposition levels are not measured but deduced from the deposition levels of ^{137}Cs and have a signifant uncertainty spread, due to varying ^{137}Cs/ ^{131}I ratios at different locations, according to the report.
- In view of the short halflife of ^{131}I (8.04 days), it is important to know at which moment after the release from the reactor the dispersion map has been made.
- During the first days to months after the accident the exposure to ^{131}I must have been substantial, also in the 'non-contaminated' areas. The health effects may have long incubation times.
- If an area has been contaminated with ^{131}I, then also the long-lived radioisotope ^{129}I is present. The contamination levels and the health hazards of ^{129}I are not discussed in UNSCEAR 2000 Q548.

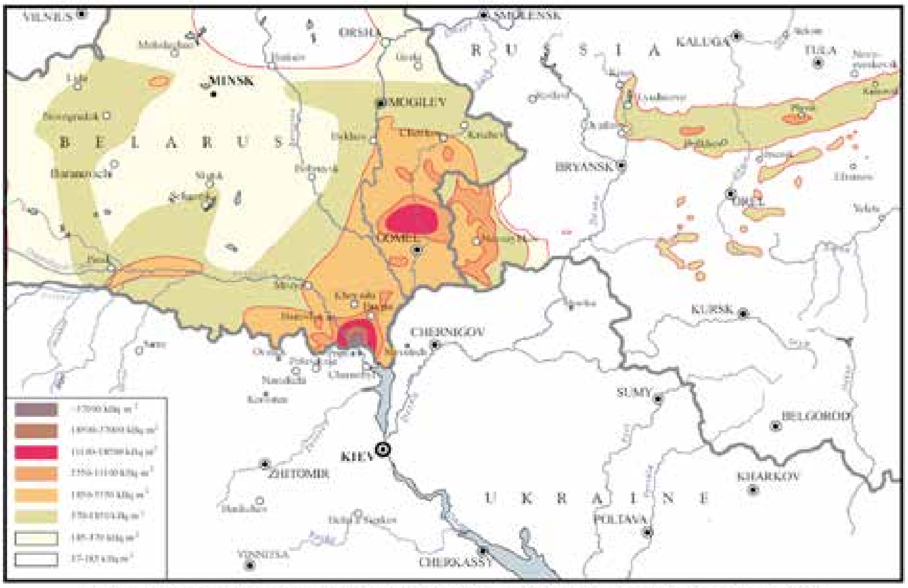

Figure X. Estimated surface ground deposition in Belarus and western Russia of iodine-131 released in the Chernobyl accident [B25, P19].

Figure 7

Estimated surface ground deposition in Belarus and western Russia of iodine-131 released in the Chernobyl accident. Source: [UNSCEAR 2000] Q548.

3 View of WHO and UNSCEAR on the Chernobyl catastrophe

Uncertainties

The effects of a large nuclear accident are exceedingly serious, the more so because radioactive contamination is practically irreversible. The exposure of the residents in the affected areas to radioactive contamination is not limited to the period of the disaster, when the radionuclides are being dispersed into the environment. The gaseous radionuclides released during the accident rapidly disperse into the atmosphere and so are diluted to very low, but still measurable concentrations around the globe. Within a short period the bulk of the short-lived radionuclides, for example ^{131}I (half-life 8.04 days) have decayed into stable nuclides. For above reasons it is difficult to assess the doses radionuclides people are exposed to during the days and weeks immediately following the disaster.

In the long run the non-gaseous radionuclides are deposited on the ground and a number of them will enter the food chain. Via food and water the contamination with long-lived radionuclides will last nearly forever. The health effects of chronic exposure to low concentrations of a mix of radionuclides is not systematically investigated. Statements that low concentration do not harm, or even would be beneficial (hormesis) are not based on empirical data. On the contrary, results from may studies, among other the KiKK and Geocap studies, prove that concentrations far below the official safe threshold values are harmful and can cause cancer deaths and other diseases.

WHO 2011a report

The report of the World health Oranization [WHO 2011a] is based on the report of the United Nations Scientific Committee on the Effects of Atomic Radiation [UNSCEAR 2011] Q571. After the publication date of these reports the WHO and UNSCEAR apparently focused on Fukushima. This section summarises a number of statements from the WHO report and comments on them. [WHO 2011a] Q570 states:

> The main radionuclides to which individuals were exposed were iodine-131, caesium-134 and caesium-137.

From this statement seems to follow that other radionuclides, including actinides, were not taken into account in the WHO study. As explained above, dozens of different radionuclides were dispersed over vast areas. The possibility of contamination by other radionuclides is not mentioned by the WHO.

In 2011, the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) published *New report on health effects due to radiation from the Chernobyl accident* [Q571]. According to this report the findings were based on more than two decades of experimental and analytical studies of the health consequences of radiation exposure from the Chernobyl accident. The report is stated to be “the most comprehensive evaluation to date of exposure levels and health effects from the Chernobyl accident”.
The following quote is in conflict with studies by independent institutes and organizations, for example the International Physicians for the Prevention of Nuclear War (IPPNW).

> …, there is no clearly demonstrated increase in the incidence of solid cancers or leukaemia due to radiation in the exposed populations. There also is no convincing proof so far of increases in other nonmalignant disorders that are related to ionizing radiation.

Denial by the WHO and UNSCEAR of deleterious health effects caused by exposure to radioactive materials is confirmed by the following quote from [WHO 2011a]:

> Since 1986, there has been a reported increase in congenital malformations in both contaminated and uncontaminated areas of Belarus which predated Chernobyl and may be the result of increased registration of such

cases. Based on dose levels to which the majority of the population was exposed, there is unlikely to be a major effect on the number of stillbirths, adverse pregnancy outcomes, delivery complications, or the overall health of children, but monitoring remains important.

This statement shows that the UNSCEAR and WHO base their reports on model calculations, and not on empirical evidence. From other statements in the reports, not quoted here, follows also that large epidemiological studies, the only method to reliably investigate the relationship between health effects and radioactive contamination, did not form the basis of the findings of the WHO and UNSCEAR reports. No indications are found in the reports that such studies are being planned for the future.

Note that the qualification 'uncontaminated' just means a deposition of less than 40 kBq/m² of Cs-137. As explained in the previous section these 'uncontaminated' areas are almost certainly contaminated by numerous other radionuclides of which the presence has not been ascertained experimentally. Even if each of those unmeasured radionuclides would have a surface activity of less than 40 kBq/m², the joint activity may be a multiple of this criterium. The health hazards in the 'uncontaminated' areas may be substantial, the more so if the health effects of chronic exposure to many different radionuclides simultaneously are also taken into account.

The next part of this section discusses some quotes from [WHO 2011a] Q570.

Cancers

For the last two decades, attention has been focused on investigating the association between exposure to radionuclides released in the Chernobyl accident and late effects, in particular thyroid cancer. In the first few months after the accident, radiation dose exposures to the thyroid received were particularly high in children and adolescents living in Belarus, Ukraine and the most affected regions of the Russian Federation, and in those who drank milk with high levels of radioactive iodine. By 2005, more than 6,000 thyroid cancer cases had been diagnosed in this group. It is most likely that a large fraction of these thyroid cancers are attributable to radioiodine intake. Furthermore, it is expected that increases in thyroid cancer incidence due to the Chernobyl accident will continue for many more years, although long-term increases are difficult to quantify. Apart from the dramatic increase in thyroid cancer incidence among those exposed at a young age, there is some indication of increased leukaemia and cataract incidence among workers. Otherwise, there is no clearly demonstrated increase in the incidence of solid cancers or leukaemia due to radiation in the exposed populations. There also is no convincing proof so far of increases in other nonmalignant disorders that are related to ionizing radiation.

There is a tendency to attribute increases in rates of all cancers over time to the Chernobyl accident, but it should be noted that increases in cancer in the affected areas were also observed before the accident. Moreover, a general increase in mortality has been reported in recent decades in most areas of the former Soviet Union, and this must be taken into account when interpreting the results of the accidentrelated studies.

Persistent psychological or mental health problems

Several international studies have reported that exposed populations, compared to controls, had anxiety symptom levels that were twice as high and were more likely to report multiple unexplained physical symptoms and subjective poor health. Given that rates of mental health problems increase after a disaster and may manifest years after the event, WHO recommends improving availability and access to normal community mental health services in disaster-affected areas.

One of the objectives of the on-going UN inter-agency International Chernobyl Research and Information Network (ICRIN) project5 (see below) is to alleviate the stigma of psychological trauma in society, encourage self-reliance, and empower local communities to take control over their own lives. One of the ways to achieve these goals is to promote healthy lifestyles, including physical activity and healthy diet, and to explain the environmental, behavioural, and other risks for various chronic diseases, including cancer.

Concerns related to fertility and birth defects
In the Chernobyl-affected regions, there is no evidence of decreased fertility among males or females in the general population. However, birth rates may be lower in contaminated areas because of a high rate of medical abortions.
Since 1986, there has been a reported increase in congenital malformations in both contaminated and uncontaminated areas of Belarus which predated Chernobyl and may be the result of increased registration of such cases. Based on dose levels to which the majority of the population was exposed, there is unlikely to be a major effect on the number of stillbirths, adverse pregnancy outcomes, delivery complications, or the overall health of children, but monitoring remains important.

Potential impact on health in other European countries. So far, there has been no clear evidence of any measurable increases in adverse health effects related to the Chernobyl radiation in countries outside of Belarus, the Russian Federation and Ukraine.

Currently, concentrations of radioactive cesium -137 in agricultural food products produced in areas affected by the Chernobyl fallout are generally below national and international standards for actions. In some limited areas with high radionuclide contamination (e.g. in parts of the Gomel and Mogilev regions in Belarus and the Bryansk region in the Russian Federation) or areas with organic poor soils (the Zhytomir and Rovno regions in Ukraine), milk may still be produced with activity concentrations of Cs-137 that exceed national standards for action (100 Becquerel per kilogram). In these areas, countermeasures and environmental remediation may still be warranted.

Wider impacts of the Chernobyl accident
In countries beyond those most directly affected, Chernobyl triggered questions concerning the safety of crops, milk, food, and water; the effects of radiation exposure on different population groups; and the kind of preventive measures that were to be put in place. In many countries, the accident prompted important political discussions regarding the use of nuclear energy and national energy policies.
Chernobyl underscored the critical need for international coordination and cooperation related to environmental hazards. Chernobyl also prompted UN agencies to develop international agreements and arrangements for nuclear emergencies. In 1986, two international conventions were adopted by the IAEA's General Conference: the Convention on Early Notification of a Nuclear Accident and the Convention on Assistance in the Case of Nuclear Accident or Radiological Emergency. WHO, which is a party to both conventions, set up the Radiation Emergency Medical Preparedness and Assistance Network - WHO REMPAN - in 1987. Today, the network includes more than 40 centres world-wide specialized in radiation emergency medicine, dosimetry, diagnosis and treatment of radiation injuries, public health interventions and long-term follow-up.

(end of quotes from [WHO 2011a])

UNSCEAR 2011 report

Report [UNSCEAR 2011] is named *New Report on Health Effects due to Radiation from the Chernobyl Accident*. Despite new research data becoming available, the major conclusions regarding the scale and nature of the health consequences of the 1986 Chernobyl accident are "essentially consistent" with previous assessments", the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) says. Among the 173-page report's findings are:

- 134 plant staff and emergency workers suffered acute radiation syndrome (ARS) from high doses of radiation

- In the first few months after the accident 28 of them died
  Although another 19 ARS survivors had died by 2006, those deaths had different causes not usually associated with radiation exposure, the report said
- Skin injuries and radiation-related cataracts were among the most common consequences in ARS survivors
- Although several hundred thousand people, as well as the emergency workers, were involved in recovery operations, there is no consistent evidence of health effects that can be attributed to radiation exposure, apart from indications of increased incidence of leukemia and of cataracts among those who received higher doses.

Regarding the general public in the three most affected countries, the only evidence of health effects due to radiation is an increase in thyroid cancer among people exposed as children or adolescents in 1986. There were more than 6,000 cases reported from 1991 to 2005 in Belarus, Ukraine and four most affected regions in the Russian Federation. By 2005, 15 of the cases had proven fatal, the report said. A "substantial portion" of the cases could be attributed to drinking milk in 1986 contaminated with short-lived iodine-131 from the accident.

Otherwise the report reconfirmed that radiation doses to the general public in the three most affected countries were relatively low and most residents "need not live in fear of serious health consequences". In the areas of Belarus, the Russian Federation and Ukraine defined as "contaminated areas" by the former Soviet Union, because of higher soil levels of the long-lived caesium-137, the average additional dose over the period 1986-2005 is "approximately equivalent to that from a medical computed tomography scan". The report said that the severe disruption caused by the accident resulted in "major social and economic impact and great distress for the affected populations".

The report also says that 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."

One of the findings of the report [UNSCEAR 2011] is:

> Although several hundred thousand people, as well as the emergency workers, were involved in recovery operations, there is no consistent evidence of health effects that can be attributed to radiation exposure, apart from indications of increased incidence of leukemia and of cataracts among those who received higher doses.

This statement contradicts the findings of other studies, such as: [TORCH 2006], [Greenpeace 2006] [Yablokov *et al*. 2009], [UCS 2011], [Yablokov 2011].

Unclear is the meaning of the following statement from [UNSCEAR 2011]:

> And because of "unacceptable uncertainties in the predictions," the Committee decided not to use models to project absolute numbers of effects in populations exposed to low doses.

4 Health effects: disparities in estimates

Estimates of the number of deaths and non-lethal diseases that resulted and will eventually result from the Chernobyl accident vary widely.

The WHO [WHO 2005] Q498 and the IAEA ([AEA 2008] Q497 insist that 'less than 50' people died from radiation exposure at Chernobyl. Obviously the IAEA counted only deterministic effects: those persons who died within days or weeks after the explosion, due to direct exposure to high levels of radiation from the wrecked reactor (acute radiation syndrome, ARS). The WHO roughly estimated that cancer deaths caused by Chernobyl may reach a total of about 4000 among the 5 million persons residing in the contaminated areas. The report went into depth about the risks to mental health of exaggerated fears about the effects of radiation. According to the IAEA the "designation of the affected population as 'victims' rather than 'survivors' has led them to perceive themselves as helpless, weak and lacking control over their future". The IAEA says that this may have led to behaviour that has caused further health effects.
More details are discussed in section 4.10, IAEA Chernobyl Forum.

According to an analysis based on radiological data provided by UNSCEAR, the Union of Concerned Scientists estimates that, among the hundreds of millions of people living in broader geographical areas, there will be 50 000 excess cancer cases resulting in 25 000 excess cancer deaths [UCS 2011] Q522. For this broader group, the TORCH report [TORCH 2006] Q521 predicts 30 000 to 60 000 excess cancer deaths.
A Greenpeace report puts the figure at 200 000 or more [Greenpeace 2006] Q519.

A major study originating from the affected regions [Yablokov et al. 2009] Q419, based on 5000 scientific papers published in Russia, Belarus and Ukraine, cites a death toll of the Chernobyl disaster worldwide of 985000 people. Independent scientists in the USA and Canada estimated the global deathtoll, including future cases, at 0.9 – 1.8 million people [Yablokov 2011] Q565. Some 400 million people have been affected by the Chernobyl fallout. According to Yablokov the IAEA bases its estimate on 300 exclusively Western papers.

Yablokov mentions 90 000 cases of cancer in Europe alone; apart from thyroid cancer a incidence of brain tumors with childern, leukaemia and brest cancer are observed. These cancers are caused not only by radioiodine, but also by radioactive tellurium, cesium and other radionuclides.
Acoording to Yablovkov the largest part of excess deaths resulting from Chernobyl are caused by cardio-vascular diseases, not by cancer. In addition to various cancers and cardio-vascular diseases Yablokov mentions various other non-cancer diseases, which are well documented and the high incidence of which has to attributed to the Chernobyl disaster, among other:

- chromosome damage
- malformations with new borns
- radiation-induced cataract
- vascular vegetative dystony (the "new Chernobyl syndrome")

Much evidence can be deduced from public health statistics from before and after Chernobyl. Also it is possible to compare the health condition of the population in heavily contaminated and lightly contaminated regions.
More than 300 000 people are evacuated from their town or village. More than 6 million people are living in significantly contaminated areas. It is unclear if their health will be monitored [Yablokov 2011] Q565.

5 IPPNW 2011 report

By coincidence one month after the nuclear disaster at the Fukushima Daiichi niclear power plants in Japan, the report *Health effects of Chernobyl, 25 years after the reactor catastrophe* [IPPNW 2011] Q452 was published. The report is written by a team of authors from the German Affiliate of International Physicians for the Prevention of Nuclear War (IPPNW) and of the Gesellschaft für Strahlenschutz.
The IPPNW 2011 report is based on large numbers of analyses, which were found comprehensive and methodically sound, not only papers that have been published in peer-reviewed journals. There are a lot of serious analyses from scientists in Russia, Belarus and Ukraine which have been published in Russian and discussed at congresses in Russian. They are almost completely ignored in the Western world.

One of the findings of the IPPNW study is:

> "Essential data on the course of events of the Chernobyl catastrophe and the subsequent effects on health are not publicly available. They are classified in both East and West. This makes independent scientific analysis of the effects of Chernobyl extremely difficult. The United Nations pro-nuclear organs such as the IAEA are attempting – with the use of questionable scientific methods – to minimise the effects of the catastrophe by inaccurate use of Chernobyl data. From a scientific point of view, this is unacceptable."

The number of liquidators, that are the people who helped to clean up the site of Chernobyl and to construct the sarcophagus to cover the exploded reactor, is estimated at 600000 - 1 000000 people. It is not clear if these people worked voluntarily, under pressure, knowingly or in ignorance; they were exposed to high, but unknown levels of radioactivity. As early as 1992 some 13000 liquidators had died and 70000 were invalid, according to a source in Minsk. On basis of a number of studies the death toll among the liquidators in 2005 is estimated at 112000 - 125000 people. Other sources estimate that 50000 - 100000 liquidators have died. In 2005 94% of the surviving liquidators were ill or invalid, according to the Ukrainian embassy in Paris.

Available studies estimated the number of fatalities among infants to be about 5000. According to UNSCEAR between 12000 and 83000 childern were born with congenital deformations in the region of Chernobyl, and around 30000-207000 genetically damaged childern worldwide. Only 10% of the expected damage can be seen in the first generation.

In some areas in Belarus and Ukraine nearly all habitants are suffering from one or more radiation-induced diseases.
The IPPNW study cites may other observed consequences of the Chernobyl disaster. One of the conclusions of the study reads:

> By 2050 thousands more cases of illnesses will be diagnosed that will have been caused by the Chernobyl nuclear catastrophe. The delay between cause and noticeable physical reaction is insidious. Chernobyl is far from over.

Radiation-induced diseases

In the regions contaminated with radioactivity after the Chernobyl disaster a greatly increased incidence of a many different maligne and non-maligne diseases and disorders are observed, such as:

- multimorbity classified as radiation-induced premature senescence
- cancers and leukaemia
- thyroid cancer and other thyroid diseases
- damage to nervous system, mental disorders
- heart and circulatory diseases
- infant mortality
- congenital malformations
- endocrinal and metabolic illnesses

- diabetes
- miscarriages and pregnancy terminations
- genetic damage, hereditary disorders and diseases
- teratogenic damage, such as:
  anencephaly, open spine, cleft lip/palette, polydactylia, muscular atrophy of limbs, Down's syndrome.

Societal and economic effects

The spatial extent of the Chernobyl disaster is illustrated by Figures 1 and 2. The human suffering and economic damage can only be guessed from that chart. Hundreds of thousands of people, particularly the evacuees from the 30 km zone, having lost their home and job, ended up in a situation of serious societal disruption, apart from the many physical disorders and diseases.

The economic damage and losses of the Chernobyl disaster are not easily to define and to assess. According to the Chernobyl Forum [ChernobylForum 2006] Q523 is in Belarus the total cost over 30 years estimated at US$235 billion (in 2005 dollars). The on-going costs are better defined; in their report, The Chernobyl Forum stated that between 5% and 7% of government spending in Ukraine still related to Chernobyl, while in Belarus over $13 billion is thought to have been spent between 1991 and 2003, with 22% of national budget having been Chernobyl-related in 1991, falling to 6% by 2002. Much of the current cost is related to the payment of Chernobyl-related social benefits to some 7 million people across the 3 countries.
A significant economic impact at the time was the removal of 784,320 ha (1,938,100 acres) of agricultural land and 694,200 ha (1,715,000 acres) of forest from production. While much of this has been returned to use, agricultural production costs have risen due to the need for special cultivation techniques, fertilizers and additives, according to the Chernobyl Forum.

The costs of dismantling and cleanup of the Chernobyl site are not included in above estimates. It is not clear if cleanup is being considered a feasible option.

The IPPNW 2011 report cites the following figures with regard to the impact of the Chernobyl disaster:
- Cleanup workers 600 000 - 1 000 000.
- Evacuees from the 30 km zone and other highly contaminated zones: 350 400; other sources cite: 135 000 evacuees and 400 000 people lost their home.
- Population of heavily contamined zones in Russia, Belarus and Ukraine: 9 000 000.
- 3 000 000 people living in an area (21 000 km^2) with more than 185 kBq/m^2 cesium-137 (kilobecquerel per square meter), 270 000 people in an area (10 000 km^2) with more than 555 kBq/m^2 Cs-137.
- European population in zones with minor exposure: 600 000 000.
- Total contaminated area in Russia, Belarus and Ukraine more than 162 000 km^2.

6 IAEA Chernobyl Forum

The main conclusions of the Chernobyl Forum in 2005, published as an undated document by the [IAEA 2012] Q499, retrieved september 2012, are listed below. For unclear reasons these conclusions are not included in the main report of the Chernobyl Forum, published in 2008 [IAEA 2008] Q497 and which has not been updated since, as far as known.

1. The Chernobyl accident in 1986 was the most severe nuclear accident in the history of the world nuclear industry. Due to the vast release of radionuclides it also became the first rate radiological accident. However, after a number of years, along with reduction of radiation levels and accumulation of humanitarian consequences, severe social and economic depression of the affected Belarusian, Russian and Ukrainian regions and associated serious psychological problems of the general public and emergency workers became the most significant problem.

2. The majority of the more than 700 000 emergency and recovery operation workers and five million residents of the contaminated areas in Belarus, Russia and Ukraine received relatively minor radiation doses which are comparable with the natural background levels; this level of exposure did not result in any observable radiation-induced health effects. An exception is a cohort of several hundred emergency and recovery operation workers who received high radiation doses; of whom approximately 50 died due to radiation sickness and its consequences. In total, it is expected that radiation has caused, or will cause, the premature deaths of around 4000 people from the 600 000 affected by the higher radiation doses due to the Chernobyl accident.
   Another cohort affected by radiation are children and adolescents who in 1986 received substantial radiation doses in the thyroid due to the consumption of milk contaminated with radioiodine. In total, about 4000 thyroid cancer cases have been detected in this cohort during 1992–2003; more than 99% of them were successfully treated.

From this conclusion may follow that the IAEA only deaths by radiation sickness (Acute Radiation Syndrome ARS) and a limited number of thyroid cancer deaths recognises as radiogenic. Apparently other radiogenic health effects are denied.
Questionable from a scientific point of view is the statement: '*comparable with the natural background levels*'.
How does the IAEA define *background levels?* Why aren't they quantified?
Which kinds of radiation and/or radionuclides are accounted for?
To which kind of radiation refers it? The activity of a number of radionuclides, for example tritium, carbon-14, iodine-129 and a number of actinides are not or hardly measurable by commonly used radiation counters, but are harmful inside the body.
'Background level' is an elastic notion: When is it measured (if measured at all): before of after the Chernobyl accident? Where is it measured: in an 'uncontaminated' area? Or elsewhere?
What is the meaning of the classification '*comparable*'?

3. Radiation levels in the environment have reduced by a factor of several hundred since 1986 due to natural processes and countermeasures. Therefore, the majority of the land that was previously contaminated with radionuclides is now safe for life and economic activities. However, in the Chernobyl Exclusion Zone and in some limited areas of Belarus, Russia and Ukraine some restrictions on land-use should be retained for decades to come.

4. Countermeasures implemented by the Governments in coping with the consequences of the Chernobyl accident were mainly timely and adequate. However, modern research shows that the direction of these efforts must be changed. Social and economic restoration of the affected Belarusian, Russian and Ukrainian regions, as well as the elimination of the psychological burden of the general public and emergency workers, must be a priority.
   Another priority for Ukraine should be the decommissioning of the destroyed Chernobyl Unit 4 and the safe management of radioactive waste in the Chernobyl Exclusion Zone, as well as its gradual remediation.

5. Targeted research of some long term environmental, health and social consequences of the Chernobyl accident should be continued for decades to come. Preservation of the tacit knowledge developed in the mitigation of the accident consequences is essential.

6. This report is the most complete on the Chernobyl accident because it covers environmental radiation issues, human health consequences and socio-economic consequences. About 100 recognised experts in the field of Chernobyl-related research from many countries, including experts from Belarus, Russia and Ukraine, have contributed to it. This report is a consensus view of the eight organisations of the UN family and of three affected countries.

The conclusions of this IAEA Forum are strikingly different from the conclusions of the study [IPPNW 2011] Q452. Apparently the Forum limited its scope to specific groups of the population and/or to specific areas and/or to one specific disease (thyroid cancer). It expects about 4000 premature deaths among 600 000 people, probably this group includes, or are, the liquidators (a word seldom used by the IAEA), far less than the figures cited by other studies, such as: [TORCH 2006], [Greenpeace 2006], [Yablokov *et al.* 2009], [UCS 2011] and [Yablokov 2011]. The above conclusions point to the conviction of the IAEA and the WHO that non-cancerous diseases and cancerous diseases other than thyroid cancer, cannot be caused by radiation. Psychological problems among the general public and emergency workers are seen as the most significant problem.

Conclusion 4 makes the impression of a non-committal statement, without suggestions how to achieve a safe remediation. Notable is also phrase in the conclusion quoted above:

> This report is the most complete on the Chernobyl accident ...

This statement sounds untrustworthy, because the results of other studies are not included in the report, and not even mentioned. The report [Chernobyl Forum 2008] was published in 2008 and was not updated since, as far as known, a fact already pointed to by IPPNW and Yablokov. The report does not list the names of the 'about 100 recognised experts in the field of Chernobyl-related research', so it is unclear who attributed to the report.

In its 2003-2005 report [Chernobyl Forum 2006] Q523 states:

> The number of deaths attributable to the Chernobyl accident has been of paramount interest to the general public, scientists, the mass media, and politicians. Claims have been made that tens or even hundreds of thousands of persons have died as a result of the accident. These claims are highly exaggerated. Confusion about the impact of Chernobyl on mortality has arisen owing to the fact that, in the years since 1986, thousands of emergency and recovery operation workers as well as people who lived in 'contaminated' territories have died of diverse natural causes that are not attributable to radiation. However, widespread expectations of ill health and a tendency to attribute all health problems to exposure to radiation have led local residents to assume that Chernobyl-related fatalities were much higher.

The Chernobyl Forum pays extensive attention to the radiation doses people in the contaminated areas may have contracted. The reported indicence of health effects (e.g. leukaemia, solid cancers, circulatory diseases) seem to be based on these dose estimates and old models. Noticeable is the following quote from [Chernobyl Forum 2006]:

> Because of the relatively low dose levels to which the populations of the Chernobylaffected regions were exposed, there is no evidence or any likelihood of observing decreased fertility among males or females in the general population as a direct result of radiation exposure. These doses are also unlikely to have any major effect on the number of stillbirths, adverse pregnancy outcomes or delivery complications or the overall health of children.

Noticeably absent in the reports of the IAEA/UNSCEAR/WHO are discussions on the possible effects of (often chronic) contamination by radionuclides, internally by inhalation and ingestion via food and water,

and of the possible synergistic effects of contamination by a number of different radionuclides. In the reports the notion ‘radiation’ is consistently used, without referring to the biochemical properties of the involved radionuclides.
No mention can be found in the IAEA publications of the necessity of epidemiological studies. The report [UNSCEAR 2000] is right when it states:

> There is no scientific evidence of increases in overall cancer incidence or mortality or in non-malignant disorders that could be related to radiation exposure.

The only way to acquire scientifically reliable evidence may be by means of epidemiological studies.

The World Nuclear Association states in [WNA-*chern* 2016]:

> Subsequent studies in Ukraine, Russia and Belarus were based on national registers of over one million people possibly affected by radiation. By 2000, about 4000 cases of thyroid cancer had been diagnosed in exposed children. However, the rapid increase in thyroid cancers detected suggests that some of it at least is an artifact of the screening process. Thyroid cancer is usually not fatal if diagnosed and treated early, and all but nine children were successfully treated.
> In February 2003, the IAEA established the Chernobyl Forum, in cooperation with seven other UN organisations as well as the competent authorities of Belarus, the Russian Federation and Ukraine. In April 2005, the reports prepared by two expert groups – “Environment”, coordinated by the IAEA, and “Health”, coordinated by WHO – were intensively discussed by the Forum and eventually approved by consensus. The conclusions of this 2005 Chernobyl Forum study (revised version published 2006) are in line with earlier expert studies, notably the UNSCEAR 2000 report which said that “apart from this [thyroid cancer] increase, there is no evidence of a major public health impact attributable to radiation exposure 14 years after the accident. There is no scientific evidence of increases in overall cancer incidence or mortality or in non-malignant disorders that could be related to radiation exposure.” As yet there is little evidence of any increase in leukaemia, even among clean-up workers where it might be most expected. However, these workers – where high doses may have been received – remain at increased risk of cancer in the long term. Apart from these, the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) says that “the great majority of the population is not likely to experience serious health consequences as a result of radiation from the Chernobyl accident. Many other health problems have been noted in the populations that are not related to radiation exposure.

7 Observable effects in the environment

The consequences of the radioactivity for the plant and animal life in the contaminated regions have been and are still being investigated by a number of scientists in the USC Chernobyl + Fukushima Research Initiative at the University of South Carolina. See [Mousseau 2014] Q610 for a list of the more than 60 completed studies and results and the goals for 2014-15.
One of the findings are the adverse effects on the growth of pine trees in the contaminated areas, see the striking photograph in Figure 8 below.

One may wonder what are the long-term effects of radioactive contamination for humans, in view of the pronounced effects for trees? It seems improbable that chronic exposure to many different radionuclides, even at 'low' levels, would not have health effects.

Figure 8

Difference in width of tree rings in pine logs from Chernobyl. The year of the accident in 1986 is clearly visible from the change in color of the wood. This is Figure 3 from [Mousseau et al. 2011] Q615.

8 Dismantling of Chernobyl

Shortly after the disaster a shield was hastely built around the destroyed reactor, called the 'sarcophagus', by 600000- 1000000 workers, called the 'liquidators'. These people must have contracted high doses of radiation and contamination by all radionuclides escaping from the destroyed reactor, and as a result thousands of them have died during the years after 1986 [Yablokov *et al*. 2009], [IPPNW 2011].
The sarcophagus is seriously deteriorating and is in danger of collapsing. An international consortium decided to build a large confinement around the destroyed reactor to be able to dismantle the sarcophagus and the reactor in a safe way by means of remotely piloted equipment.No cost estimates of the dismantling are published as far as known, nor estimates of the time period that may be needed.

Figure 9
New Safe Confinement at the site of Chernobyl. On the left the 'sarcophagus' of the destroyed reactor is visible. This structure, hastely built in 1986, is seriously deteriorating and is in danger of collapsing. Source photo: [Mammoet 2016]. After completion the shelter was moved in November 2016 into place, covering the entire sarcophagus.

The New Safe Confinement will prevent the release of contaminated material from the present shelter and at the same time protect the structure from external impacts such as extreme weather. The New Safe Confinement has a mass of 36200 Mg, is 108 metres high and 162 metres long, and has a span of 257 metres and a lifetime of a minimum of 100 years. It provides a safe working environment equipped with remotely piloted heavy duty cranes for the future dismantling of the shelter and waste management after the completion of the NSC.It is strong enough to withstand a tornado and its sophisticated ventilation system eliminates the risk of corrosion, ensuring that there is no need to replace the coating and expose workers to radiation during the structure's lifetime [ebdr 2016a].The total cost of the Shelter Implementation Plan, of which the New Safe Confinement is the most prominent element, is estimated to be around €2.15 billion (US$2.3 billion). The New Safe Confinement alone accounts for €1.5 billion [wiki-NSC 2017].
A significant part of the costs of the shelter are funded by the European Commission [WNA-*chern* 2016].

The word confinement is used rather than the traditional containment to emphasize the difference between the 'containment' of radioactive gases that is the primary focus of most reactor containment buildings, and the 'confinement' of solid radioactive waste that is the primary purpose of the New Safe Confinement.

9 Critical notes

Reading of the reports by the IAEA, UNSCEAR and WHO on the Chernobyl disaster and its consequences gives cause for critical notes and questions, some of which are summarised below.

- According to the IPPNW there are many serious analyses, published in Russian from scientists in Russia, Belarus and Ukraine, that are almost completely ignored in the Western World.
How reliable are the reports of the IAEA, UNSCEAR and WHO?

- The quantity of released radioactivity is a controversial issue, stated figures vary from 1.85 - 185 exabecquerel. This spread by a factor 100 may point to different methods of estimation.
Are the reported quantities actually measured, or are they a result of a model calculation?
If measured, which kind of radiation is measured: alpha + beta + gamma, or only gamma?
At which moment after the disaster are the quantities of released radioactive materials measured/calculated?
Which radionuclides are accounted for and which not?

- The reports of the IAEA/UNSCEAR/WHO state that less than 50 deaths are caused by the Chernobyl disaster. Independent studies come to figures of up to 1 million deaths.
This discrepancy points to fundamentally different approaches of attributing lethal consequences to the nuclear disaster.
A factor may be the moment of assessment of the lethal consequences: shortly after the disaster, or during many years thereafter taking the long latency periods (years to decades) into account.
Another factor may be the fact that the IAEA/UNSCEAR/WHO do not recognise non-cancerous diseases as possible effects of exposure to radioactivity.

- In the reports of the IAEA/UNSCEAR/WHO no references are found to other studies and their results, not even the names are mentioned. Without referring to any particular publication critiques are attributed to 'ignorance' and 'fear of the unkown'.
From these observations speaks a tendency to avoid a dialogue and discourse on scientific arguments.

- Indifference and apathy of the IAEA/UNSCEAR/WHO is shown in the reports towards the countless incidences of non-malignant, but serious diseases and disorders, that are downplayed as 'radiophobia', 'bad lifestyle', 'culture of chronic dependency', role of invalids and victims'.
Apparently in the view of the IAEA/UNSCEAR/WHO these disorders are not induced by radiation and are not typical for nuclear accidents and therefore do not fall under the responsibility of the nuclear industry.
Indifference also towards the hundreds of thousands of people lost their home, job and social infrastructure as a result of forced evacuation.
Even if all those people would not be contaminated by radioactivity, the displacement and human suffering has been caused by a nuclear disaster.

- Radiological models turn out to play a dominant role in the official assessment of the Chernobyl disaster.
Observed effects that do not fit the models are attributed to other causes than radiation without scientific proof, or are ignored.

- The UNSCEAR decided not to use models to project absolute numbers of effects in populations exposed to low dose, because of what it calls 'unacceptable uncertainties', without clarifying the meaning of 'unacceptable'.
If models are unable to provide the desired data, a sound scientific investigation may do the job?
What is the eaxct meaning of 'absolute' numbers? There always will be an uncertainty spread in this kind of

assessments.
No mention is found in the publications of the IAEA/UNSCEAR/WHO of the necessity of epidemiological studies, perhaps the only method to prove the relationship between health effects and radioactivity. Epidemiological studies have to be continued for many years involving large cohorts of people.

- This study found no discussion on the possible effects of prolonged or chronic exposure to a broad gamut of radionuclides via food and drinking water, via inhalation of gases and dust. During the Chernobyl disaster dozens of different radionuclides were dispersed into the environment. Alpha and beta radiation is hardly or not detectable by commonly used radiation counters, but alpha and beta emitters are hazardous inside the body.

- Discussing the health effects resulting from the Chernobyl disaster the reports of the IAEA/UNSCEAR/WHO consistently use the notion 'radiation'. Not clear is which kind of radiation is meant: alpha + beta + gamma, or only gamma? The classic radiologic models are based on gamma radiation and X-rays from sources outside of the body.
Biochemical properties of radionuclides are not incorporated into the models, as little as possible synergistic effects caused by a number of radionuclides simultaneously.

- UNSCEAR published maps of the dispersal of only a few radionuclides caused by the Chernobyl disaster: Cs-137, strontium-90, iodine-131 and plutonium-239 + 240.
It remains unclear how these maps have been established: based on measurements? based on models? at which date?
For what reason no other dispersal maps have been published? Due to the different physical and chemical properties of the many released radionuclides, their dispersion patterns might differ from the patterns of Cs-137, I-131 and Sr-90.

- The water of the river Pripyat, flowing at a short distance of the exploded reactor through the most heavily contaminated area, must have transported large amounts of all kinds of radionuclides to the lake 'Kiev Reservoir'. This occurred during prolonged periods, and may still going on.

- The dispersal map of iodine-131 raises a few questions.
No estimates have been published of the I-131 deposition in Ukraine, for unexplained reasons. The border of Ukraine with Belarus is also the border of the indicated I-131 deposition, indicated in Belarus and Russia. In view of the short half-life of I-131 (8.04 days), it is important to know at which moment after the release from the reactor the dispersion map has been made.
During the first days to months after the accident the exposure to I-131 must have been substantial, also in the 'uncontaminated' areas. The health effects may have long latency periods.
If an area has been contaminated with I-131, then also the long-lived radioisotope I-129 is present. The contamination levels of I-129 are not mentioned by UNSCEAR.

- The IAEA/UNSCEAR/WHO reports paid little or no attention to the dispersion of tritium (symbols T, H-3, or ^{3}H) and carbon-14 (symbols C-14 or ^{14}C). For what reason?
Both radionuclides are biochemically very reactive (see also Chapter 3), and the released amounts of both radionuclides must be very large. Likely the complete inventory of tritium in the coolant and in the molten fuel elements escaped into the environment as T_2O and HTO. Likely a part of the tritiated water rained down. The burning graphite moderator of the Chernobyl reactor must have contained massive amounts of carbon-14 and a substantial part of it must have escaped as $^{14}CO_2$. Likely this radioactive gas was globally dispersed.
It may have been of interest if UNSCEAR also composed maps of the plumes of the escaping tritium and carbon-14 from Chernobyl.

- UNSCEAR published a dispersal map of Pu-239 + 240. If Pu-239 and Pu-240 escaped, the other plutonium isotopes also escaped, because the plutonium isotopes are chemically identical. The half-lifes of Pu-238 and Pu-241 (87.8 respectively 15 years) are much shorter than the half-lifes of Pu-239 and Pu-240 (24390 resp. 6540 years) so their specific activity is much higher than that of Pu-239 and Pu-240. As a result the total plutonium activity in the contaminated and 'uncontaminated' areas must be significantly higher than indicated in the map.
UNSCEAR does not mention the presence of isotopes other than Pu-239 and Pu-240 in this context.

- As a result of the burning moderator and accompanying steam and hydrogen explosions a substantial part of the non-volatile elements from the molten fuel elements escaped as dust and possibly as high-temperature volatile compounds, including uranium, plutonium and other actinides.
If plutonium isotopes escaped then also uranium (including its strongly radioactive isotopes U-232, U-234 and U-236), neptunium-237, americium-241 and other actinides escaped, because of their similar chemical properties. Consequently the radioactivity of the contaminated areas might be a multiple of the activity indicated by UNSCEAR on the dispersal map.
IAEA, UNSCEAR and WHO do not mention the dispersion of neptunium, americium and other actinides.

- Actinides like plutonium, neptunium and americium are bone seekers after ingestion: they tend to accumulate in the bone marrow. Inside the body their alpha radiation is extremely damaging to living tissue. During the years following the dispersion of uranium and the actinides the amounts of their decay products in the contaminated areas are steadily rising. These decay daughters are also hazardous to living organisms.

- On its dispersal maps of Cs-137, Sr-90, I-131 and Pu 239 + 240 UNSCEAR indicates contaminated areas and 'uncontaminated' areas. An area is classified as 'uncontaminated' if the activity of the involved radionuclide is below a certain limit (37 kBq/m^2, in case of Pu-239 + 240: 3.7 kBq/m^2).
During the disaster dozens of different radionuclides escaped from the destroyed reactor contaminating the areas indicated in the maps. As a result the cumulative radioactivity of contaminated and 'uncontaminated' areas must be higher than indicated in the maps. As a consequence the areas with a contamination level above the chosen limit are likely significantly larger than indicated in the maps.
It is unclear if the presence of other radionuclides than the above mentioned was or still is being monitored.

- The detailed character of the UNSCEAR dispersal maps raises some questions.
Are the activities of the involved radionuclides measured within a short time period? At which moment afer the disaster? The number of measuring points must have been very large.
If the maps are the result of model calculations and a limited number of measurements, the extent of the presented spatial details seems difficult to explain.
The graphite moderator and molten fuel of the destroyed reactor burned for ten days and consequently the dispersion of radionuclides continued for at least ten days, probably longer, until the reactor was covered by a hastely built structure, called the sarcophagus. In view of a constantly changing direction of the wind during ten days or longer a dispersion pattern as presented by UNSCEAR seems unlikely.
The dispersion map of Cs-137 in Figure D.1, made by the French Centre d'Enseignement et de Recherche en Environnement Atmospheric (CEREA), presents a dispersion picture quite different from the UNSCEAR map in Figure D.2. UNSCEAR made not clear how its dispersion maps have been established.

- The detailed character of the dispersion map of plutonium and other actinides is questionable for the same reasons as explained in the previous note. Actinides and other non-volatile radionucldes escaped from the burning reactor as dust and aerosols. Satellite photos of dust blown from the Sahara desert across the Atlantic to Florida show how far solid particles can be transported by the wind.

- The detailed dispersal maps may suggest a permanent situation. However, it is unlikely that the dispersal

patterns would be permanent, likely the patterns change continuously due to different causes.
One factor is the redispersion of radionuclides by wild fires, human activities, transport of contaminated materials and biomass and other causes.
Another factor is related to the solubility of radioactive materials in water. Cesium-137 compounds for example are highly soluble in water, like all cesium isotopes, so its dispersal pattern may change continuously by rain and flowing water. This holds also true for other soluble radioisotopes.

- What happened and is still happening with the numerous deposited radionuclides, including the hazardous actinides, in the soil and groundwater, soluble and insoluble in water?

Bioaccumulation of radionuclides may be also a point of concern: how is the present situation? What are the consequences of bioaccumulation for food and water for the inhabitants of the affected areas?

- It is unclear on which scientific grounds UNSCEAR bases its definition of 'uncontaminated' areas.

Does it mean that no harmful health effects can be expected in those 'uncontaminated' areas? This conclusion may be related with the trend within the IAEA/UNSCEAR/WHO to deny health effects of 'low' doses of radiation. Concerning health effects caused by radioactivity IAEA/UNSCEAR/WHO speak only about radiation, not about internal contamination by radionuclides via food, drinking water and inhalation of dust and aerosols, as pointed out in one of the previous notes.

- As pointed out earlier, an area classified as 'uncontaminated' with respect to, for example, Cs-137 may be more or less heavily contaminated by other radionuclides. Different radionuclides may exhibit different dispersion patterns, due to different chemical and physical properties.

In case of the dispersal map of plutonium-239+240 a second effect is at issue: the similar physical and chemical behaviour of the not-named plutonium isotopes and of the other actinides, resulting in a higher radioactivity level of the contaminated and 'uncontaminated' areas than indicated on the UNSCEAR maps.

- In their reports the IAEA/UNSCEAR/WHO often use the notion 'low' dose/doses.

What is the criterion of the classification 'low doses'?
To which kind of radiation refer the IAEA/UNSCEAR/WHO with their classification 'low doses', alpha + beta + gamma, or only gamma?
Do these institutes refer to radiation only from Cs-134, Cs-137 and I-131?
What about the radiation from the dozens of other kinds of radionuclides present, that were not monitored by UNSCEAR in the contaminated and 'uncontaminated' areas? The contributions of all radionuclides in a given area are cumulative. Ten times a 'low' dose may become a high dose.

- A complicating factor is the fact that a number of biochemically reactive radionuclides, such as tritium, carbon-14 and iodine-129, are not or hardly detectable by commonly used radiation counters. The beta radiation of these hazardous radionuclides does not contribute to the radiation level at a given site. The same holds true for some hazardous alpha emitters.

- Discussing the health effects of the dispersal of radionuclides the IAEA/UNSCEAR/WHO frequently use the notions 'background level' and 'comparable to the background level'.

How do the IAEA/UNSCEAR/WHO define the 'background level'? Do they use a quantified criterion?
'Background level' is an elastic notion: When is it measured (if measured at all): before of after the Chernobyl accident? Where is it measured: in an 'uncontaminated' area? Or elsewhere?
Also in another respect is 'background level' an elastic notion. Likely the content of radionuclides in the air, soil and water increased with time due to the discharges from the Chernobyl disaster. Even in areas not affected by the disaster the radioactive content may rise due to the authorised discharges of nuclear power plants and reprocessing plants.
What is the meaning of the classification 'comparable'? Which margins has the IAEA in mind, 2 times, 10

times, 100 times the ‘background level’?

- The effects of a large nuclear accident are practically irreversible. The exposure of the residents in the affected areas to radioactive contamination is not limited to the period of the disaster, when the radionuclides are being dispersed into the environment. People living in the contaminated areas, but also in the ‘uncontaminated’ areas, are chronically exposed to a gamut of radionuclides, via inhalation of dust and via ingestion of contaminated drinking water and food grown on contaminated soil.

- The gaseous radionuclides released during the accident rapidly disperse into the atmosphere and so are diluted to very low, but still measurable concentrations around the globe. Within a short period the bulk of the short-lived radionuclides, for example I-131 (half-life 8.04 days) have decayed into stable nuclides. For above reasons it is difficult to assess the doses radionuclides people are exposed to during the days and weeks immediately following the disaster.

- In the long run the non-gaseous radionuclides are deposited on the ground and a number of them will enter the food chain. Via food and water the contamination with long-lived radionuclides will last nearly forever. The health effects of chronic exposure to ‘low’ concentrations of a mix of radionuclides is not systematically investigated. Statements that low concentrations do not harm are not based on empirical data. On the contrary, results from independent studies prove that concentrations far below the official safe threshold values are harmful and can cause malignant diseases.

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