Health consequences of Chernobyl disaster in Europe in general and in Norway in particular. Literature review and ecological study.

HEL-3950

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Introduction.

It's been 26 years since Chernobyl disaster happened. It changed people's attitude towards nuclear energy and raised the level of accident alertness and safety on the nuclear facilities. But those are the only effects of Chernobyl that appear in straightforward and obvious way. When it comes to health costs, consensus is not yet achievable. As C. Busby points out in a methodology of the ECRR, predictions about the scope of Chernobyl consequences for public health vary between almost none (according to UN agencies – among them WHO, UNSCEAR, IAEA etc.) to 1, 8 million cancers (Rosalie Bertell 2006). The reasons for these disparities are different assessment of the range of contamination, its composition, and ultimately doses received by the population. (Busby 2011).

Another source of disagreement is the on-going debate about the risks of getting different conditions (e.g. cancers) from low-dose radiation exposure. At the moment we extrapolate observed risks at higher doses to predicted risks of lower doses. We also assume the non-threshold effect of low-dose radiation. Whether there is a linear, quadratic or other type of function, that describe dose-risk relationship, it has not been agreed upon but linear no-threshold model is most often used. (BEIR VII). The only way to estimate the factual form of the curve is to conduct epidemiological studies with subsequent observational trails. (Pflugbeil et al).

Main goal of this paper therefore is to investigate health consequences of Chernobyl disaster in Europe (outside the former Soviet Union) as a whole and in Norway in particular as one of the second high contaminated areas after those in the immediate vicinity of the Chernobyl nuclear power plant. In order to do that an ecological (correlational) hypothesis-generating study has been conducted to assess the relationship between this major catastrophic nuclear event and cancer epidemiology in Norway. Based on the present knowledge about the biological effects of the radiation the main outcomes chosen are cancer incidence and prevalence in the timeframe from 1966 and until 2009. Two periods – 1966-85 and 2006-2009 in two most polluted areas of Norway are compared in terms of incidence rates. Cesium 137 is considered as a main indicator compound of radioactivity. The presence or the absence of the health-related aftermaths of the disaster can also serve as an evaluation of the effectiveness of vast bulk of countermeasures that were launched in order to secure the population from detrimental radioactive agents.

The study has used data from the Cancer Registry of Norway. The interpretation and reporting of these data are the sole responsibility of the authors, and no endorsement by the Cancer Registry of Norway is intended nor should be inferred.

The main structure of this paper

Part I. Literature review.

1. In the first part of the paper the **background of the disaster** is given from UN agencies (UNSCEAR, IAEA and WHO) and peer reviewed literatures point of view. Further the **composition and distribution of radioactive fallout** described

2. After mapping the fallout, **effects of radioactive isotopes on local ecosystems are explored and the accumulation of radioisotopes on different trophic levels assessed.**

3. The main **routs of exposure** and the most **vulnerable groups** are defined afterwards.

4. Calculated **doses** for the population are given in the next section.

5. **Biological effects of the radiation and toxicokinetics of relevant radionuclides** are described next.

6. Some **criticism** of conventional point of view on these issues is presented as data is put forward.

Part II. Epidemiological study.

7. In the second part information on **frequency of health outcomes** of interest in the population of affected geographical areas is obtained.

8. **Statistical analysis** is performed in order to answer the main question of the paper followed by a chapter with analysis of possible **flaws and methodological weaknesses** of present study.

9. At the very end **conclusions** are drawn and possible suggestions of further exploring of the topic are brought about.

Sources of information

I searched for peer review literature in PubMed and Cochrane library. Most of the literature I found was individual articles as well as reviews and overviews of the articles. I also used reports of UNCSEAR, IAEA, NEA as well as relevant books on the subject. To conduct ecological study I used data from the Cancer Registry of Norway.

Part I.

Background.

On 26 April 1986, during the conduction of an experiment on the unit 4 reactor of Chernobyl nuclear power plant, shutting down of electrical power system of the

facility caused overheating of the fuel followed by 2 explosions, fire and reactor's core melting. As a result a cloud containing fuel, core components, fission products and structural items was shut into the atmosphere (World Nuclear Association 2009). Instantaneously after the explosions, fire started in graphite component of the reactor, causing a large plume of radioactive smoke to occur. Due to weather conditions the lower layer of plume turned North-West polluting significant areas in Northern hemisphere with radioactive substances. Only Southern hemisphere remained intact (NEA 2002.) Because of the cold war situation at that time the information on the explosion were retained from the public and international community by Soviet government and only registration of the elevated levels of radionuclides in the countries of Fenoscandia (first in Sweden) revealed that a serious nuclear catastrophe had happened in the south-western part of former Soviet Union. Among the countries in Europe radioactive fallout covered especially areas of Belarus, Ukraine, Russia and Fenoscandia along with parts of Austria, Eastern and Southern Switzerland and Southern Germany. (NLVF 1992)

Fallout composition. Source term.

Source term is an expression used to denote release of radioactive materials to the environment. It is determined by the initial core inventory (Table 1), type of the destructive process (e.g. fire) and environmental (weather) conditions. Information on source term is obtained by two main methods of quantification of the amount of the radionuclide release. The first one is based on estimating reactor core radionuclide inventory in the moment of accident and then multiplying the amount of a particular radionuclide by its fraction that was released into the environment. The second one consists in direct measuring of the concentration of radionuclides deposited around the ChNPP (Chernobyl Nuclear Power Plant) assuming that territories in the immediate vicinity received full specter of emitted radionuclides. (UNSCEAR 2011).

When assessing source term one should consider amount of the radioactive materials released, physical and chemical forms of radionuclides, distribution of the radioactive compounds over time. (OECD NEA 2002).

1. **Amount of the radioactive materials** released is determined by the building elements of the reactor commonly called core inventory. ***Core inventory*** characterization of Chernobyl reactor at the moment of disaster required information on how much fuel had already burned up in the reactor when it exploded. To estimate that one had to measure fuel burn –up (how much energy over time is produced by 1 tone of fuel.), and then, knowing energy produced and time, calculate the amount of fuel in tons. According to UNSCEAR, 3, 5 +_ 0, 5% of fuel material has escaped which corresponds to the total amount of 6 tons of fragmented fuel. Total core inventory along with percentage and activity of release of its components is presented in Table 1. It has been estimated that total activity of fallout was 1, 2 x 10^{19} Bq. (1 Bq is SI unit that corresponds to 1 nuclear disintegration per second.). So activity of a particular element depends on the speed of its nuclear disintegration.

The amount of I 131 activity released was 1, 2-1, 7 x 10^{18} Bq. Cs 137 component added 3,7x 10^{16} Bq. (UNSCEAR 2011)

2. **Chemical composition** of the source term (radioactive release) from Chernobyl exposure was presented by about 100 different radionuclides. Most important are shown in Table 2. The biggest fraction that escaped from reactor is presented by noble gases (100% of it escaped at once) such as Xe along with fission products – 50-60% of I 131, 25-60% of tellurium 132 and 20-40% of cesium 134 and 137. **Physical forms** were represented by *gasses* (xenon, krypton and partly I 131), *aerosols* formed by other volatile elements (I, Cs and Te.) and *fuel particles,* composed mostly of the low volatile elements or condensates of previously vaporized fuel. Fuel particles had different aerodynamic size. Larger fragments (> 50 μm) settled down in the vicinity of the nuclear power plant. 80 to 90 % of their activity was due to non-volatile radionuclides. (Zr 95, Nb 95, La 140, Ce 144 and transuranium elements). Smaller fuel fragments (<20 μm) contained among others "hot particles" – metallic particles that were condensed from vaporized fuel (ruthenium – about 10 μm in size, Cs 137 and originally particulate I 131 0, 4- 0, 7 μm) and reached countries in Scandinavia, as well as Greece, Hungary and Poland. It should also be noted that relative importance of different radionuclides changes over time. Short-lived radionuclides with half-life's counted in days yielded biggest share of the dose in the first weeks after explosion, than during the first year after explosion major dose was due to isotopes of Ce, Rb, Zr and Ni. After 1987 and further Cs-137 and Sr-90 as well as transuranium elements (Pu) determine external and internal doses. (NEA 2002.)

3. **Distribution of the radioactive compounds over time**.

Exposure profile of the Chernobyl disaster was characterized by ***period of intense release*** (10 days after the accident) that in turn occurred in two stages. *In the early stage* (initial release) source term was influenced by initial explosion and mechanical fragmentation of fuel led to initial large release that contained a lot of volatile elements – such as noble gasses, vaporous I 131 and some cesium. *The second stage of a long –term release* was due to graphite fire, which started at 5.00 on Saturday, 26 April and had not been put down until 6 of May. It included cool down period (2nd to 6th day) and heat up period that led to second large release between day 7 and 10 when temperatures in the core reached extremely high level. On 11th day of the disaster release of radioactive materials dropped abruptly presumably due to penetration of the corium trough the lower biological shield and as a consequence sharp temperature decrease. In order to put down the fire huge amounts (5000t) of neutron- absorbing and fire-control materials were dumped into reactor. (NEA 2002.)

Indicators of Exposure.

If we sum up the information on half-life, radioactivity, amount in the release and physical properties we can see that there are 3 radionuclides Cs 134, Cs 137 and I 131 that are most important in the assessing the health effects of Chernobyl

disaster. Further among those 3 the main indicator of exposure over the long term period since 1986 is considered to be Cs 137. The reason for that is that two other radionuclides have short half-life period and are extinguished from the environment after 16 days (in case of I131) and 2 years (in case of Cs 134) so Cs137 remains the main contributor to the dose to the population in a long run. It is also easily measurable which makes it possible to assess radiological exposure. (UNSCEAR 2011)

Environmental fate of radionuclides.

Radioactive fallout can have form of dry sediments, aerosols or precipitation (rain or snow). Radionuclides in those compounds can be found in different physical forms – as particles, colloid or ions. Environmental fate of the radionuclides depends on those forms and the natural processes that could affect them. Fallout settlement from the air can happen directly on the soil, on plants, snow layer or a water body. Radioactive compounds that settle down directly to the topsoil layer can either go further down in to the subsoil layer (vertical transport), migrate with the soil particles carried by wind (lateral transport.) or be taken up by plant roots. Radionuclides that resided on the vegetation can further be washed of by the rain and reach soil or remain on the plant to either be consumed by the domestic or wild animals and end up in food products (such as meat and milk). Snow melting and runoff water conduce to the redistribution of the radioactivity and ultimately incorporate radioactive compounds into aquatic ecosystems and can exercise effect on humans both directly through drinking water and indirectly through "bottom sediments- aquatic plants – aquatic animal" food chain (see fig 1). There are a number of factors that can modify each step of radionuclide movement in the environment. To assess this movement, transfer factors (coefficients) are introduced.

Topsoil – vegetation transfer is described by

Transfer Factor = (concentration in the vegetation, Bq/kg)) / (concentration in the soil, (Bq/kg))

Transfer Coefficient = (concentration in the vegetation, Bq/kg)) / (soil deposition, Bq/m^2)

Concentration Ratio = radioactivity in the vegetation, (Bq/m^2)/ total deposition, (Bq/m^2)

Forage – meat transfer

F_f= (concentration in meat, Bq/kg)) / (daily intake, (Bq/day))

Forage – milk transfer

F_m= (concentration in milk, Bq/kg)) / (daily intake, (Bq/day))

Water-fish transfer

Transfer Factor = (concentration in fish, Bq/kg)) / (concentration in the water, (Bq/kg))

Soil –food products transfer is described by

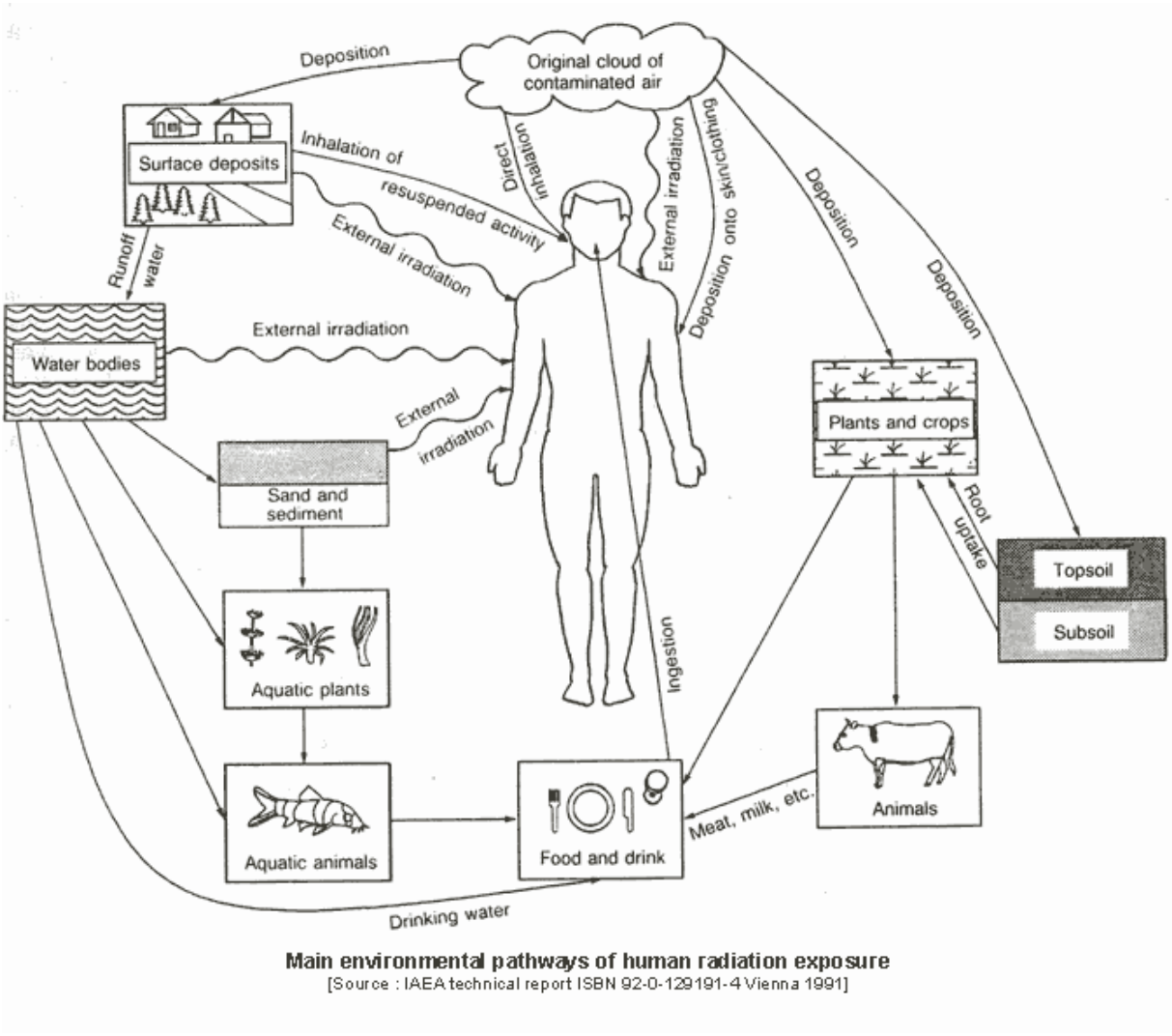
F_m = (concentration in the food product, Bq/kg)) / (soil deposition, Bq/m^2)

We can also calculate mobility factor:

MF = (mobile fraction (Bq/m2)) / (total deposition, (Bq/m2))

(T. H. Garmo, T. B. Gunnerød, 1992)

Fig 1. Routs of radiation exposure.



Main environmental pathways of human radiation exposure
[Source : IAEA technical report ISBN 92-0-129191-4 Vienna 1991]

Environmental transfer of Cs 137 in the local ecosystems.

Cs 137 is malleable, silvery white metal liquid at a room temperature. It is produced when uranium and plutonium absorb neutrons and undergo fission. (ATDSR. 2004).In the environment Cs137 from the fallout can be carried to the soil in several ways:

1. By direct deposition from the atmosphere

2. As a result of the wash-off from the plants

3. As a result of turn-over from vegetation

4. Trough re-deposition of eroded soil particles

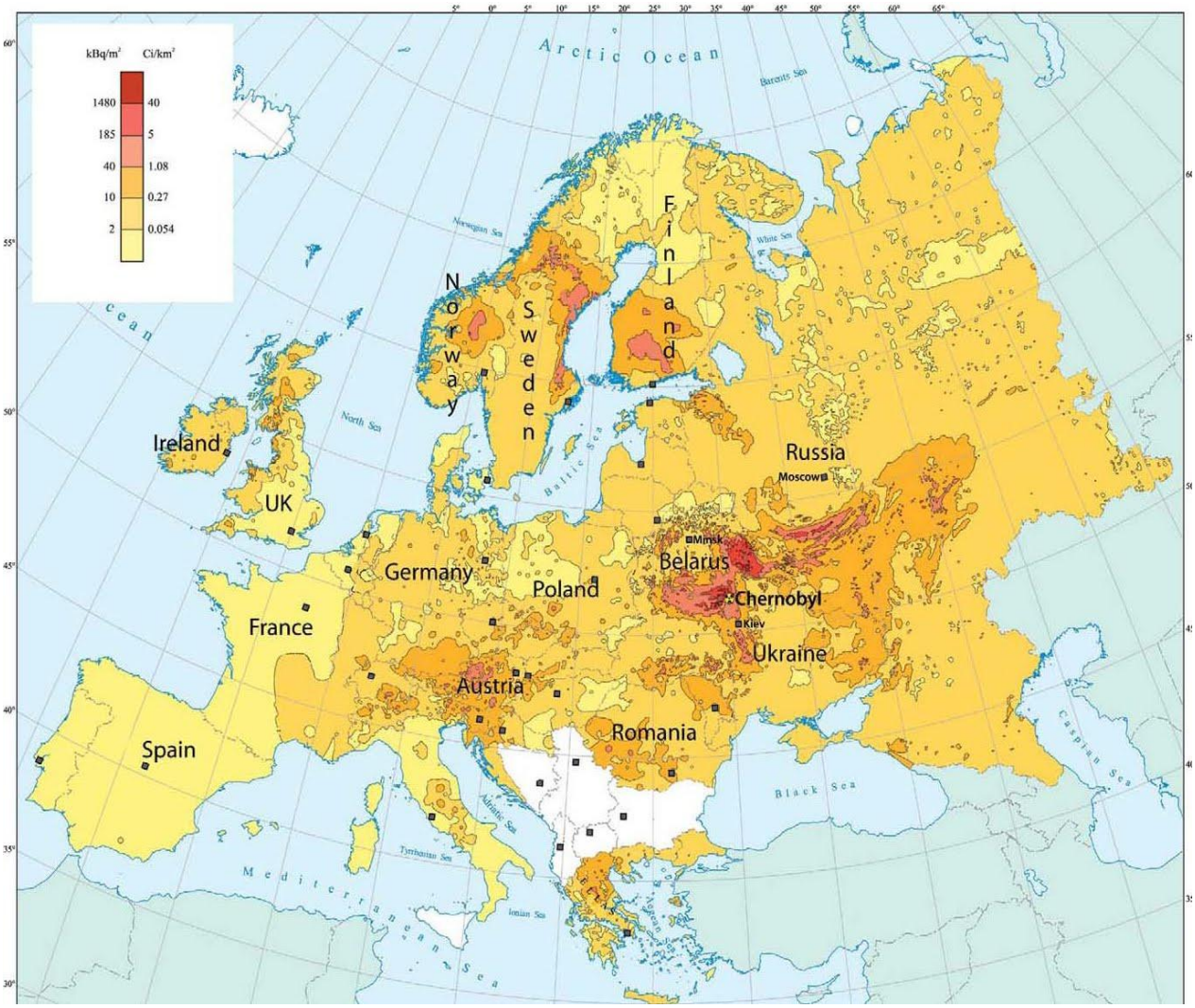
5. Due to deposition from water on floodplains and coastal regions

Absorption of Cs137 depends on the type of soil. Soils reach with clay minerals and poor with organic compounds tend to absorb Cs137 better. The presents of organic component makes binding of Cs137 to the soil particles reversible and as a result it is more readily captured by plant roots. Also presence of certain microorganisms enhances the root up-take while big amounts of Na^+ and K^+ slow that process down. ***Migration of Cs 137*** is affected both by the type of soil, its chemical composition as well as climate conditions and soil stability. In stable (non-eroded and non-mixed) soils the downward migration is very slow. In one study from Poland vertical migration of Cs137 15 years after Chernobyl was not deeper than 10 cm. Another study from Swiss alpine region revealed that 10 years from Chernobyl fallout occurred most of the Cs 137 was stowed in the upper 5 cm of the soil profile. ***Accumulation of Cs 137 on different trophic levels.*** Cs 137 than fit into the trophic structure of the ecosystem and can execute health effects through the food chains structure. Exposure routs for humans was in that case limited to ingestion and inhalation. (See fig 1). (W. Schimmack, W. Schultz, 2006)

Mapping the exposure.

According to "Atlas of cesium deposition on Europe after the Chernobyl accident" issued by Radioactivity Environmental Monitoring (REM) group the largest amounts of radioactive materials were deposited in Belarus, Ukraine and Russia. The total amount of Cs 137 deposition in the land mass of Europe is about 85 PBq (UNSCEAR 2011). In addition some amount of Cs137 was deposited in the water bodies and about 20 % escaped from Europe to settle on the other continents. Hence the total amount of Cs 137 is less than 77 PBq. The level of deposition that goes beyond 40 kBq/m2 is considered to give average annual dose to the population that exceeds 1 Msv. Areas of higher deposition hence are considered as those that have amount Cs 137 above 40 kBq/m2. These areas include: Austria, Belarus, Czech Republic, Estonia, Finland, Germany, Greece, Italy, Norway, Poland, Rumania, Russia (European part) Slovak republic, Slovenia Sweden, Switzerland, Ukraine, and United Kingdom. It should be noted however that territory polluted varies significant between all these countries. Among those where polluted areas cover more than 1000 km2 are Austria (11 000 km2), Belarus (46 000 km2), Finland (19000 km2), Norway (7100 km2), Russia (European part – 60000 km2), Sweden (24000 km2), Ukraine (38000 km2). In Western Europe Cs 137 was deposited mainly in the mountainous areas while in Eastern Europe mostly on the flat land. There were 3 countries that indicated deposition level more than 1480 k Bq/m2 – Belarus (2600 km2), Russia (460 km2) and Ukraine (560 km2). Geographically **Cs distribution can be viewed as 3 major spots** covering significant areas with most deposition in ***the***

republics of former Soviet Union (Belarus, Russia and Ukraine), second affected area in ***Scandinavia*** (Finland, Sweden and Norway) and the ***South of central Europe*** (South of Germany, Switzerland, North of Italy, Austria and Czech Republic.) Average Cs137 deposition varies between and within the countries. Generally, territories that are situated on the geographically long distance from Chernobyl demonstrate very irregular pattern of deposition.



(from "Atlas of cesium deposition on Europe after the Chernobyl accident" (http://rem.jrc.ec.europa.eu/RemWeb/pastprojects/Atlas.aspx).

Mapping the fallout. Former Soviet Union

According to UNSCEAR 2008 report there were 3 main areas of contamination in the immediate vicinity of ChNPP – Central (west, north-west of the reactor), Gomel – Mogilev- Bryansk area and Kaluga-Tula –Orel areas. Those areas received uppermost levels of radioactive fallout concentration. Radionuclide deposition was highest (1500 kBq/m^2) in the surrounding ChNPP area – 30 km zone. The total deposition of Cs 137 after adjusting for background levels is estimated to be about 40 PBq. 40% from the ascribed to Belarus, 35 % to Russia and 24 % to Ukraine. 0, 4 PBq was spread over other territories of former USSR.

Fallout in Belarus

Among other countries Belarus received largest amount of radioactive compounds. Fallout was represented also by low volatile elements and fuel particles. Entire country was covered by the fallout that contained isotopes of I-131, I-132 and Te-132 with maximum level of I-131 contamination of 600 Ci/km^2. 23% of the territory had levels of C-137 at a level higher than 37 kBq/m^2 (1 Ci/km$^{2)}$. Most affected areas were Gomel and Mogilev province with maximum value of 5402 kBq/m^2. Sr 90 was dispersed closer to the southern border (i.e. to the ChNPP) and yielded deposition of 5, 5 kBq/m^2 on the 10% of country territory. Also, 2% of the country was covered by isotopes of Pu-238. Pu-239 and Pu-240 at levels higher than 0,37 kBq/m^2. (Yablokov et al 2009).

Fallout in Ukraine

25% of Ukraine territory was covered by Cs 137 with concentrations higher than 37 kBq/m^2 on 4, 8% of the territory. (Yablokov et al 2009). Contamination happened during the period after 28 April due to rainfall that coincided with the radioactive plume passage. Contaminated regions with the Cs ground deposition higher than 37 kBq/m^2 were (form east to west) Chernigov, Kiev, Zhitomir, Rovno and Lutsk.

Fallout in European Russia.

Main contamination was in the Bransk, Kaluga, and Tula and Orel areas and resulted from the rainfall 28-29 April. Cs 1237 deposition is < 500 kBq/m^2. (UNSCEAR 2011)

Mapping the fallout. Central Europe.

Fallout in Austria.

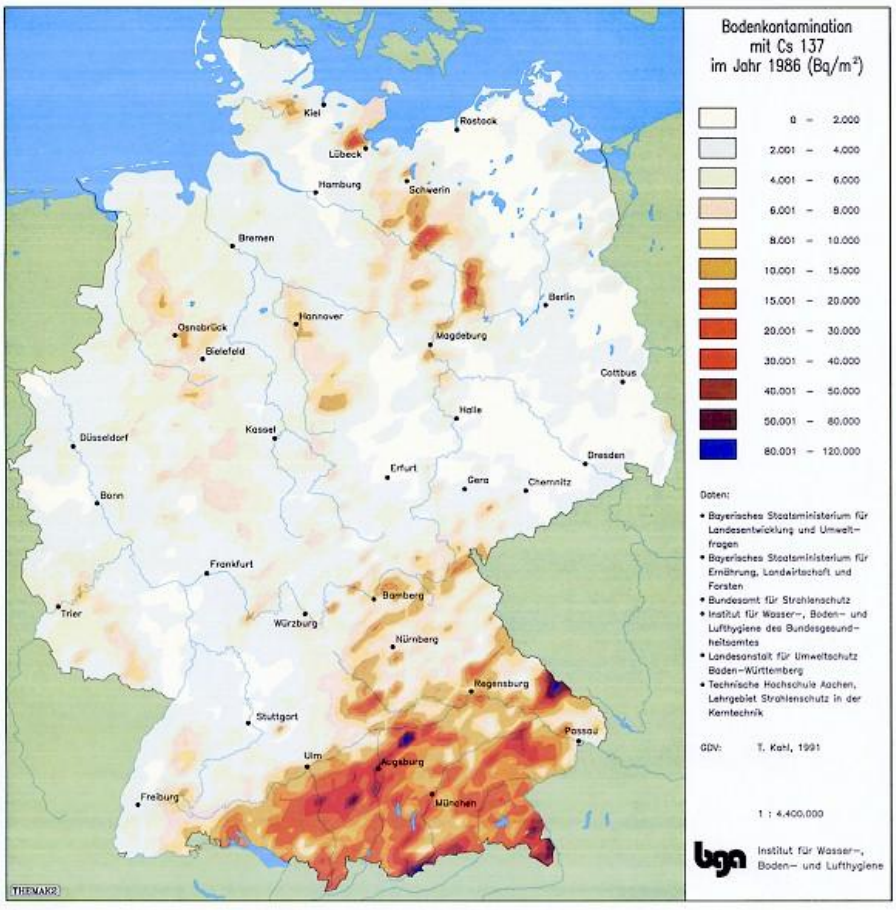
Of the average contamination of 21, 0 kBq/m^2 of Austrian soils with Cs 137, 18, 7 kBq/m^2 (89 %) is due to Chernobyl fallout. Data referring to May 1 1986 show that Austrian territory received 1, 57 PBq of Cs137 fallout which corresponds to 2% of all Cs137 that was released in the disaster. The distribution of the radioactive compound is inhomogeneous, with the maximum values nearly 200 kBq/m^2. Most affected regions are covered with mountains and forests and are contaminated due to washout by rain and snow. Cesium 137 distribution forms 2 main fallout zones – one starting in the south of the Czech republic and stretching from north-east to south-west of Austria and further to north Italy (covers counties of Nederøsterrich, Oberøsterrich, Saltzburg, Karnten and Tirol), and another one starting from west Hungary and entering southern part of Austria, covering Steiermark and Karnten) and proceeding to the alpine regions of northern Italy. (Bossew et al 2000).

Fallout in Czech Republic.

Soil contamination with Cs 137 in Czech Republic on average reaches the level of 7,6 kBq/m^2. Maximum value reached is 95 kBq/ m^2

Fallout in Germany

Fig 2. Retrieved from http://www.environmentalstudies.de/Radioecology/Radiocesium/Cs_E1/cs_e1.html)



Most of the fallout happened between April 30 and May 5, 1986 mostly in the southern part of country (Bayern).

Mapping the fallout. Fenoscandia

Fallout in Denmark

Radioactive cloud passed through the eastern part of Denmark on Sunday 27.April. It was registered in the grass samples and air filters from Risø on 28-29 April 1986. No rain occurred simultaneously so deposition was not high back than and was mostly due to dry fallout, containing low levels of Cs 137. Second wave of radionuclide emission occurred in the beginning of May, and reached Denmark on the 4 of May. This time it was accompanied by rainfall. Mean ground Cs 137 deposition was 1.29 kBq/m^2. On Farøy islands it was 2 kBq/m^2 and in Greenland 1-0, 1 kBq/m^2. (Aarkrog 1988).

Fallout in Sweden

Summary Cs 137 deposition in Sweden is estimated on the 4, 25 PBq level (Edvardson 1991). Fallout was determined by amount of rainfall as well as wet deposition mostly took place. Most contaminated territories were those in Eastern Sweden. Maximum values of 100 kBq/m^2 were registered in the eastern part of Sweden. (SGU 2005)

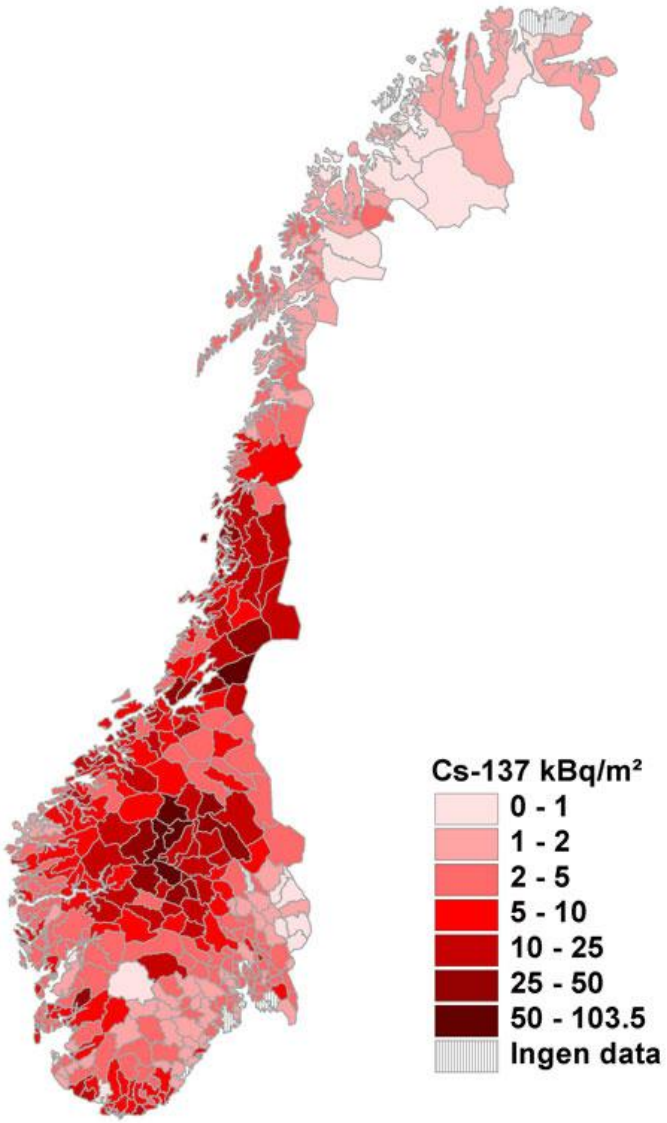
Fallout in Finland

Deposition occurred 28-30 April. Average Cs deposition was estimated on 10,7 kBq/m^2 level. Southern Finland was the most affected area. (Arvela et al 1988)

Fallout in Norway

According to the report of Agricultural Research Council of Norway radioactive deposition in Norway was related to the early stage of Chernobyl disaster. Radionuclides in different physical forms and chemical composition were identified both in the air samples and in the fallout. Main physical forms were fuel particles, condensed particles, colloids and other low molecular forms. Measuring of the radioactivity was conducted with the use of air filters, counters on planes and helicopters and regular gamma-spectroscopy of outfall samples along with soil, grass, mosses and lichens. Due to weather conditions radioactive cloud covered Norway in to waves. For the first time increase in gamma-activity and Cs 137 concentration was registered 28 – 30 April in Kjeller and Værnes and 30 April to 5 Mai in Tromsø. Second wave followed 5 – 10 Mai in Kjeller, Værnes and Bergen and 9-12 Mai in Tromsø. Most of the fallout happened by wet deposition with the rainfall. Fallout deposition therefore correlated with the amount of rain and to what degree radioactive compounds were settled down with the rainwater. The most exposed areas in Norway were parts of Buskerud, Oppland, Nord-Trøndelag and Southern part of Nordland. (fig. 3; Stråleverninfo 5.01). Soil samples showed wide variety of the I131 and sum of Cs 134 and 137 Cs concentrations within short distance, especially in the alpine regions of Østlandet. This fact indicates that redistribution happened after the initial deposition of radionuclides. Lateral transport in the form of snow melting led to forming of “hot spots” areas where radionuclides were stored. Those areas are usually represented by land depression and, as Cs137 concentration in the melt water in 1989 was measured on the level of 0,5 Bq/l, main redistribution apparently took place in spring of 1986. In the course of the first year Chernobyl radiation dose contribution was 7% from the overall dose. (NLVF1991). There were 4 major radionuclide of concern that fallout in Norway contained - I131, Cs 134, Cs137 and Sr90. Since physical half-life is 8, 04 days for I131 and 2.1 years for Cs134 and Sr 90 deposition corresponded to 1% of Cs compound, Cs 137 is considered as main radionuclide of interest in Norway too. Transfer coefficients calculated in Norway showed significant variation (10 -100 fold) between regions. Mobility factors did not produce that kind of disparity and were used in the modeling. (NLVF 1991)

Figure 3. Cesium 137 fallout in Norway



(Retrieved from http://www.nrpa.no/dav/46e8d285cd.pdf)

Doses to population after Chernobyl disaster.

Types of doses.

Dose is the amount of contaminant that actually gets into the body. In radiobiology we discern between external and internal doses. Both of them make small but persistent contribution to the overall dose. Measurement units of doses according to SI are Gray (GY) and Sieverts (SV). **Absorbed dose** is energy deposited per unit mass. It does not say anything about biological effect of the radiation however, as later also depends on the type of radiation. In order to account for type of radiation coefficients are used. Dose that is accounted for type of radiation by coefficient is called **equivalent dose**. Units for absorbed equivalent dose are Gray (conventional unit - rad). **Effective dose** is a weighted equivalent dose to the tissue (organ) depending on its radio-sensitivity. It is a measure of biological risk and it's measured in Sieverts (conventional unit - rem). (CDC 2003).Main sources of dose received were radioiodine (thyroid dose) and radiocesium (whole body dose). Long term health effects are mainly due to whole body absorbed dose.

Doses for population in Europe.

Outside Soviet Union estimated doses varied between countries. In Europe thyroid dose in the first few weeks was 1 to 20 mGy, and whole-body doses 0,05 to 0,5 mGy. It should be noted however that whole-body dose is considered more detrimental than thyroid. Highest doses were in the areas where the most rainfall occurred. UNSCEAR points out those average national doses for European population in the first year were less than 1 mSv and were decreasing afterwards. (UNSCEAR 2011). Summarizing the levels of doses Sztanuik et al. divided Europe in

regions – North, Central, Southeast, West, Southwest. Doses are usually assessed over time and are presented as dose rate per year. (see Table 4).

Region in Europe	1st year thyroid dose in infants	1st year thyroid dose in adults	1st year effective dose equivalent (μSv)	Total effective dose commitment (μSv)
North	1,0	0,5	210	970
Central	7,65	1,35	280	930
Southeast	10,7	2,9	380	1200
West	1,25	0,3	50	150
Southwest	<0,1	<0,05	<5	<10
Altogether	5,5	1,2	200	680

(from Sztanyik et al 1991)

Doses to Norwegian population.

Norwegian authorities established acceptable doses on the level of 5 mSV in the first year and 1 mSV in the following years. Both whole-body measurements and diet studies was conducted in order to assess effective dose and its major components. In 1996 diet study was conducted in south Sami reindeer herders and general public in Oppland was conducted. Main results in Mid/South Norway showed that general concentration of Cs 137 both for women and men corresponded to specific activity of 126 Bq/kg. Average effective dose per year was estimated to be 0, 3 mSv (0, 2 for women and 0, 4 for men) which is lower than the danger level of annual dose of 1 mSV. (SNT rapport 1992) According to BEIR V Report the risk of cancer death from chronic radiation is 0,04% per 10 mSv. Study also showed time trend with the highest doses in 1988 and 1989 that from then on was descending. Diet examination revealed that all participants consumed rein deer meet and it accounted for 72% of the entire meet in the diet.

Toxicokinetics of Cs 137.

It is considered that Cs 137 metabolism imitates those of K^+. Research on the Cs 137 gastro-intestinal absorption that was made on rats yielded several findings. First of all, absorption happens in to stages – initial high speed absorption is followed by slower uptake period. Secondly, food consumption slows down the rate of absorption. Thirdly, small intestine is the site with the most rapid and full Cs137 uptake and the rate of absorption are very slow for the stomach and caecum, even though to some degree all parts of alimentary tract are able to absorb it. (W. Moore et al 1962). It is unclear to what degree we can transfer those results to humans. People can be exposed to Cs 137 externally or internally. External dose is due to

radioactive deposition of radiation emitters in the environment whereas internal dose is due to food contaminated by Cs 137.

Biological effects of ionizing radiation.

The scope of effects is determined by a particular type of radiation but key mechanism is excitation of molecules in a tissue and either direct of indirect DNA damage. Impairment of the genes that represent the basis for DNA reparation system and double-strand breaks are considered as most important as cell loses fully or partially its ability to restore DNA. Main outcomes of the DNA damage are cell death (at high doses and dose rates – deterministic short-term effect) as well as chromosomal aberration, malfunctioning and malignant transformation due to disrepair of the DNA. The former are called stochastic radiation effects but they are not radiation specific. Therefore they cannot be measured directly and we extrapolate risks from high–dose effects to low-dose effects. Besides, according to The British Journal of Radiology, also non-targeted effects (effects that occur in the neighboring to the irradiated cells) of radioactivity can influence radiation risk. (IARC 2001)

Health effects of Chernobyl.

Cancer is considered as the main health effect after Chernobyl fallout. It should be noticed that among all carcinogenic agents ionizing radiation is easiest measured and best studied. All organs can develop cancer as a result of radioactive exposure but different organs have different radio sensitivity. According to UNCSEAR leukemia is one cancer that is associated with radioactivity. Studies on atomic bombings survivals showed that this effect occurs usually 2-5 years after exposure. It is also observed that solid cancers can arise but they have a longer latent period of 10 years or more. Cancer risk is also a function of age in which radioactive exposure happened. (UNSCEAR 1994).

US National Academy of Sciences BEIR VII committee concluded that linear non-threshold model of risk of health effects for low-doses of radiation. We assume that any dose of ionizing radiation lead to harm and say that frequency of occurrence of these harmful effects is proportional to the rate of high dose effects. According to those extrapolation Chernobyl disaster will add only 0, 01% to the natural incidence of cancer in Europe. This increase is hardly possible to spot in the studies but as we are not sure of the tenability of extrapolation of risks epidemiological studies should be carried out to confirm or prove this suggestion wrong.

It has been approved that I131 released in the Chernobyl explosion contributed significantly to the internal thyroid dose and led to the increase of thyroid cancer in children in the former Soviet Union. (Gilbert et al 2002, UNSCEAR 2011). One population-based study from Northern England analyzed and compared incidence rates of thyroid carcinomas in 1968-1986 and 1987- 1997 time periods. It revealed statistically significant increase in incidence rates, which was consistent with hypothesis of increased incidence of differentiated thyroid cancer in children after Chernobyl fallout. (S.J. Cotterill et al 2001).

Solid cancers and leukemia are considered the most important health effects from the whole-body dose from Cs137 (Kirsten B Moysich et al 2002). However when it comes to solid cancers they are often latent and excess risk estimate can be difficult to calculate.

There were suggestions about increase in leukemia among the liquidators. When it comes population on less contaminated areas (<37, 5 kBq/m2) of the former Soviet Union no increase in risk of solid cancers and leukemia were proven and there is little evidence of dose–response relationship between radiation from Chernobyl and solid cancers risk according to the WHO Expert Committee (Health effects of the Chernobyl accident: an overview).

One literature review from 1996 shows that in a range of epidemiological and case-control studies no change in morbidity of leukemia in Bulgaria, Greece, Germany, Hungary was observed. One study from Romania demonstrated increases of Incidence rates in 3 most contaminated regions but concluded that those increases were not because of the contamination. In Finland and Bulgaria non significant increases was found in most contaminated areas. In Turkey significant increases took place but study was weak methodologically (no age adjustment, no tenable cancer registries for earlier periods). Finally in Sweden non-significant increase in acute LL incidence in children aged 0-5 took place in the most contaminated regions according to a descriptive study (Halmars et al 1994.). No dose-response relationship was proven for solid cancers in Germany and Hungary. (Davide Sali et al 1996).

One paper from Sweden (Tondel at al) included a cohort of 1137106 inhabitants' age 0 to 68 in the moment of disaster that were living in the 8 most polluted counties of Sweden was observed. Exposure levels were calculated for participants and exposure categories established. During the follow up (1988 -1999) statistical data on cancer were assessed. Study suggests increased incidence of malignant tumors in polluted areas of Sweden after Chernobyl disaster happened.

Criticism imposed to the assessment of Chernobyl disaster.

1. The character of the explosions has been a subject of disagreement. The conventional point of view as well as independent TORCH report says that there were steam explosion, followed by apparent explosion of the hydrogen. (UNSCEAR, Fairlie and Sumner 2006). Rudi Nussbaum however referred to a Russian study (Checherov 2006) saying that explosions due to low-yield nuclear reaction (http://ehp03.niehs.nih.gov/article/fetchArticle.action?articleURI=info%3Adoi%2F10.1289%2Fehp.115-a238). If it's true, the amount of release is underestimated by the factor of 26 and 95% of the fuel was emitted into environment. Official position does not support this suggestion, saying the amount of radioactive fuel emitted equals 3, 5 %.

2. There are disagreements with respect to the amount radiation emitted. Alternative data (by Fairlie and Sumner 2006) suggested that Europe got 68 to 89% of the

gaseous- aerosol radionuclide mixture that was distributed extremely non-uniform as wind changed its direction several times and rainfall happened in only some areas.

3. There is a disagreement in what the doses were and what the effects of the doses are. A starting point in the discussion is that any, even very small, amount of radiation can lead health consequences. Assessments of the effect of chronic radiation on population suffer indistinctness in terms of the size and relative importance of Chernobyl nuclear accidents. Yablokov et al argues that problem is polarized due to vested interests of apologists of nuclear power that tend to neglect data on the size of emission, doses of radiation, and change of epidemiological indicators. He also accuses scientific community in denying non-threshold effect of the radiation and that changed risk assessment. Official position of Chernobyl forum in 2006 was that 9000 related deaths have occurred since 1986 and about 200000 people have illnesses caused by catastrophe. But the main massage that socioeconomic factors in the affected areas were more dangerous. Yablokov believes that the number of exposed are about 400 millions. He argues also that there's no scientific literature on the specific effects of particular radionuclides, populations radiosensitivity or the impact of the ultra-low doses of the radiation. Thus in his opinion simple correlation "level of radiation – effect "cannot be obtained. That is because it's wrong to combine ill-defined radiation exposure and well-defined and explicit health outcomes as it will not yield a statistical significant result. So it's a methodological problem. Furthermore as collected data by Russian field workers was not duly statistically reprocessed many of them are rejected by the international agencies as unsuitable. That can be a source of an imprecision in the process of evaluation of the health outcomes. One can argue however that including those studies in the overall analysis can be a source of significant bias. In conclusion he says that 2% added to the general radiation background can anyway trigger significant public health consequences. In any case 3 bln people inhabitant contaminated areas. More than 50 % of the territory of 13 European countries has been contaminated by Chernobyl fallout. Yablokov et al claims that it has to be an effect. His main argument is that different zones that had similar socioeconomic conditions and differed only in the level of contamination produced different public health indicators. (Yablokov et al 2009). Another point he makes is that the statistical data from the former Soviet Union are not to be trusted. Moreover Cs 137 as an indicator substance is criticized as it does not always reflect the actual accumulated effective doses. Also the type of food that was used in calculation internal dose does not represent the main dish in the local cuisine (especially if it contains mushrooms and other forest products.).

4. In the relative importance of the internal radiation as opposed to the external lead Yablokov to the anticipation of the increase in cancer morbidity in the years to come. He argues also that the prevalence of non-malignant diseases including cardiovascular and the overall health in the population suffered in the affected regions of former USSR. On the other hand available study designs restrain our ability to collect unbiased data and we should not jump in conclusions when making

the final decision. How much of the health effects can be ascribed to the accident is arguable as socioeconomic condition is considered to be a major health determinant in the modern public health.

5. There is a hinder to precision in correlational studies - the gap in the short-lived radionuclides measurement during the first days, weeks and months after the disaster, difficulties with “hot particles” effect assessment, inadequate modeling of the internal and external dose with small sample sizes. Moreover spotty distribution led to the individual dose variations that cannot be described by the average. Overlap in the distribution of different radionuclides, complicated behavior in the environment and relocating of the inhabitants further disturb the picture.

Part II.

Introduction.

As it was stated before the most affected areas in Norway were Oppland and Nord –Trøndelag counties. Uneven deposition of Cs 137 led also to differentiation of regions in terms of radioactive pollution inside those counties.

Methods

In order to systematize geographical areas of two most polluted counties I allocated their regions in 3 groups according to the radioactivity levels that were measured by the National Institute of Radiation Hygiene of Norway. (http://www.nrpa.no/dav/4707beb3e7.pdf). I estimated the cutoff points as being > 30 Bq/m^2 for group 1, 10-29,99 Bq/m^2 for group 2 and 0 – 9,99 Bq/m^2 for group 3 . As stated before the level of contamination of 40 Bq/m^2 results in the average annual doses more than 1 mSV. International guidelines set the level of acceptable dose to be 5 mSv first year and 1 mSv in the following years. When it comes to internal doses it depends on the diet. According to the Strålevern most part of the radiocesium dose (up to 60%) is due to consumption of the milk products as well as meet of cattle and reindeers were reduced due to restrictions in the agricultural sector while external doses remain. Single measurements showed dose levels higher than that acceptable but average dose to Norwegian population was in this range. Sami reindeer herders and hunters were the most exposed group of population.

Cancer statistics is presented as age- and gender-specified incidence rates of all cancers in Norway in general, in different counties of Norway, and in 3 groups described in previous segment. Overall tendency shows increase in cancer incidence over time in Norway but it is important to find out whether any particular growth occurred in the contaminated areas.

To analyze if there were any special trend of cancer incidence in the affected areas I compared Incidence rates of cancer in different age groups in Norway in general and in two most polluted counties. I looked on the 2 time periods – 1966-

1985 (before the disaster) and 2006-2009 (20 years after disaster) and calculated Incidence Rate Ratio with 95% confidence intervals. Main focus was put on the youngest age group as it is a group of the low risk and any, even small change in the incidence will explicitly manifest itself. (see figures

Zero-hypothesis (H0) for present study would be that there is no difference in IR dynamics (i.e. IRR) over time between the most affected areas and whole country and alternative hypothesis is that there is a difference.

H0: IRR (1966-85) = IRR (2005 -06)
Against
H1: IRR (1966-85) ≠ IRR (2005 -06)

IRR = IR (County) / IR (Norway)

I used Poisson model to calculate standard error of ln IRR:

$$SE\ (\ln IRR) = \sqrt{1/I_0 + 1/I_1}$$

And approximate 95 % CI for IRR

$$95\ \%\ CI = \exp\{\ln IRR \pm 1{,}96 \sqrt{1/I_0 + 1/I_1}\}$$

IRR allows us to trace the changes of cancer incidence over time and compare the rates from the most polluted areas to the overall country trend. As we have IR for Norway at the bottom, the lower the value, the lower incidence rate in a particular county. If RR takes a value of 1 than IR for a county and IR for whole Norway are equal.

Grouping and amount of cancer cases in different groups are summed up in the table 9. In Oppland the regional division was as following: group 1 included Dovre, Vågå, Sel, Vang and Øystre Sildre; group 2 – Sjåk, Nord Fron, Sør Fron, Ringebu, Øyer, Gausdal, Nordre Land, Sør-Aurdal, Etnedaland Vestre Sildre; group 3 containing Gjøvik, Lesja, Østre Toten, Jevnaker, Lunner,Gran and Søndre Land. In Nord- Trøndelag: group 1 - Frosta, Leksvik, Levanger, Verdal and Snaasa, group 2 – Steinkjer, Meråker, Inderøy, Lierne, Røyrvik, Namsskogan, Overhalla, Fosnes and Leka, group 3 – Namsos, Stjørdal, Mosvik, Verran, Namdalseid, Gring, Høylandet, Flatanger, Vikna and Nærøy.

Results.

Main results are presented in tables for Oppland and Nord- Trøndelag. IRR are given with 95 % CI.

Table 9. Cancer incidence in groups of pollution in 2 most contaminated counties.

County	Oppland			Nord-Trøndelag		
Group	1	2	3	1	2	3
1.Cancer incidence (1966-85)	1706 (m:f= 1:0.82)	2165 (m:f =1:0,96)	5407 (m:f =1:0.94)	2093 (m:f = 1:0,92)	2346 (m:f = 1: 0,91)	2961 (m:f = 1:0,9)
2.Cancer Incidence (2006-09)	610 (m:f =1:0,96)	1649 (m:f =1:0.8)	2195 (m:f = 1:0.86)	854 (m:f = 1:0,98)	952 (m:f = 1:0,91)	1170 (m:f = 1:0,872)

Oppland

Table 10. Incidence rate ratios with 95% CI, Oppland.

	Men (1966-1985)	Men (2006-09)	Women (1966-1985)	Women (2006-09)
IRR Age group 0- 29	0,96 (0,82; 1,13)	0,69 (0,58;0,83)	0,99 (0,71; 1,4)	0,65 (0,42; 1,001)
IRR Age group 30-59	0,88 (0,83; 0,93)	1,01 (0.92; 1.11)	0,91 (0,84; 0,99)	0,999 (0,922; 1.082)
IRR Age group 60+	0,83 (0,81; 0,85)	0,93 (0,89; 0,97)	0,89 (0,85; 0,93)	0,9 (0.85; 0,95)

In Oppland calculations for the youngest age group suggest rather the opposite than expected outcome. Incidence rate ratios for 0-29 age group in both men and women demonstrate significant decrease. There is, however, a measurable increase in IRR in 30-59 and 60+ age group of men and insignificant IRR increase in 30-59 age group for women. As Oppland was also divided in three groups after the range of radioactive pollution, I calculated IRR in those groups as well. Results are presented in the following tables.

Oppland Group 1

Table 11. Incidence Rate Ratios with 95% CI, Oppland Group 1

	Men (1966-1985)	Men(2006-09)	Women (1966-1985)	Women(2006-09)
IRR Age group 0- 29	0,94 (0,62; 1,43)	0,73 (0,27; 1,95)	0,76 (0,47; 1,23)	1,01 (0,42; 2,44)

IRR Age group 30-59	0,77 (0,66; 0,9)	0,95 (0,74; 1,22)	0,81 (0,71; 0,92)	1,12 (0,92; 1,4)
IRR Age group 60+	0,8 (0,75; 0,86)	0,74 (0,65;0,84)	0,88 (0,8; 0,96)	0,89 (0,77; 1,02)

In Group 1 IRR are decreasing over time in male 0-29 group, but increasing in the correspondent female 0-29 group. A clear increase in the IRR is demonstrated only in the 30-59 age groups and no change in the 60+ groups registered.

Oppland group2

Table 12. Incidence rate Ratios with CI 95%, Oppland group2

	Men (1966-1985)	Men (2006-09)	Women (1966-1985)	Women (2006-09)
IRR Age group 0- 29	0,98 (0,66; 1,46)	1,49 (0,96; 2,3)	1,05 (0,71; 1,55)	0,44 (0,18; 1,06)
IRR Age group 30-59	0,89 (0,77; 1,02)	0,96 (0,82; 1,13)	1,5 (1,34; 1,69)	1,25 (1,09; 1,44)
IRR Age group 60+	0,89 (0,84; 0,95)	0,9 (0,84; 0,97)	0,58 (0,54; 0,63)	0,5 (0,46;0,55)

In group 2 IRR rises in young male but decreases in young females. 30-59 group demonstrates an increasing trend and 60+ remains on the same level.

Table 13. Incidence Rate Ratios with 95% CI Oppland group 3

	Men (1966-1985)	Men (2006-09)	Women (1966-1985)	Women (2006-09)
	0,96	0,7	0,98	0,7

IRR Age group 0- 29	(0.76; 1.21)	(0.5; 1.44)	(0.78; 1.24)	(0.38; 1.28)
IRR Age group 30-59	0,88 (0.8; 0.96)	1,01 (0.67; 1.52)	1,01 (0.95;1.08)	0,98 (0.87; 1.1)
IRR Age group 60+	0,83 (0.8; 0.86)	0,94 (0.88;1.001)	0,9 (0.86; 0.95)	0,93 (0.86; 1.001)

Oppland group 3

Decrease in youngest males and females groups, slight increase in the 29-30 males, and slight decrease in females. 60+ group - no change. In the second most contaminated area of Nord-Trøndelag calculations yielded following perspective:

Nord –Trøndelag

Table14. Incidence Rate Ratios with 95% CI, Nord –Trøndelag

	Men (1966-1985)	Men (2006-09)	Women (1966-1985)	Women (2006-09)
IRR Age group 0- 29	0,76 (0,62 ; 0,93)	1,1 (0,77 ; 1,56)	0,75 (0,77; 0,87)	0,94 (0,62;1,42)
IRR Age group 30-59	0,89 (0,82; 0,96)	0,9 (0,63;1,28)	0,82 (0,77 ;0,87)	0,96 (0,86;1, 06)
IRR Age group 60+	0,88 (0,84; 0,91)	0,88 (0,83;0,93)	0,97 (0,93; 1,01)	0,997 (0, 94;1,06)

In 1966-88 point estimate of incidence rate ratios for men in Nord-Trøndelag were 0,76; (0,62 ; 0,93) for 0-29 age group; 0,89; (0,82; 0,96) in 30- 59 age group and 0,88 ; (0,84; 0,91) in 60 + age group correspondently.

In 2006-09 however IRR for the youngest age group 0-29 was 1,1; (0,77 ; 1,56) while remaining the same in 2 other age groups - 0,9; (0,63;1,28) for 30-59 group and 0,88 (0,83 ; 0,93) in 60+ group respectively.

IRR in women went up from 0,75 (0,77 ;0,87) to 0,94 (0,62;1,42) in 0-29 age group and from 0,82 (0,77 ;0,87) to 0,96(0, 86 ; 1, 06) in 30-59 age group (factor of 1, 17). In 60+ group IRR went up insignificantly from 0, 97 (0, 93; 1, 01) to 0,997 (0, 94; 1, 06).

Group 1 Nord –Trøndelag

Table 15. Incidence Rate Ratios with 95% CI ; Group 1 Nord –Trøndelag

	Men (1966 – 85)	Men (2006-09)	Women (1966-85)	Women (2006-09)
0-29	0, 76 (0, 51; 1, 14)	1, 59 (0, 96; 2, 65)	0,74 (0,44 ;1,23)	0,57 (0,24; 1,38)
30-59	0,8 (0,7; 0,92)	0,84 (0,67; 1,05)	0,82 (0,69; 0,98)	0,97 (0,81; 1,16
60+	0,89 (0,83; 0,96)	0,79 (0,71; 0,88)	0,98 (0,88; 1,1)	0,94 (0,83; 1,06)

IRR (1966-85) for men aged 0-29 was 0, 76 (0, 51; 1, 14) against 1, 59 (0, 96; 2, 65) in 2009-09. Wide confidence intervals include, due to small number of cases, value of 1.

Group 2 Nord-Trøndelag

Table 16. Incidence Rate Ratios with 95% CI ;Group 2 Nord-Trøndelag

	Men (1966 – 85)	Men (2006-09)	Women (1966-85)	Women (2006-09)
0-29	0,98 (0,66; 1,46)	1,49 (0,96; 2,31)	1,05 (0.52; 1.12)	0,44 (0.2; 0.98)
30-59	0,89 (0,77; 1,034)	0,96 (0,82; 1,13)	1,5 (1.34; 1.67)	1,25 (1.02; 1.53)
60+	0,89 (0,83; 0,95)	0,9 (0,8; 1,02)	0,58 (0.54;0.62)	0,5 (0.45;0.56)

Group 3 Nord – Trøndelag.

Table 17. Incidence Rate Ratios with 95% CI ; Group 3 Nord – Trøndelag.

	Men (1966 – 85)	Men (2006-09)	Women (1966-85)	Women (2006-09)
0-29	0.667 (0,44; 0,9)	0.71 (0,3; 1,71)	0.85 (0,61; 1,19)	1.24 (1,14;1,35)
30- 59	0.86	0.98	0.91	1.02

	(0,76; 0,97)	(0,82;1,17)	(0,82; 1,01)	(0,87;1,2)
60+	0.86 (0,81;0,92)	0.88 (0,8; 0,96)	0.93 (0,8;1,1)	0.91 (0,82;1,01)

Discussion.

In the 1st time period (1966 - 1985) 279006 cancers were registered in whole Norway (Male: Female = 1: 0.95). 11228 of them occurred in Oppland (M: F = 1: 0.91) and 7408 in Nord- Trøndelag (M: F= 1: 0.91).

In the 2nd time period (from 2006 to 2009)106862 cancers were registered in Norway (M: F = 1:0, 87). In Oppland cancer incidence in that period was 4454 (M:F = 0.85) and in Nord-Trøndelag 2976 (M:F = 1:0.91). As we do not have any specifications about types of cancers, all cancers without exception are analyzed. We are especially interested in the dynamics of cancer incidence of the youngest age group as any, even tiny, change in it will be easily discernible. That is because normally cancer incidence in that group is not that high.

In Oppland we can conclude that radioactive fallout did not have any influence on cancer incidence in that group as it could not possibly improve it. Slight IRR increase in 30-59 age groups adds controversy to the data, but that increase can be due to other factors.

In 1966-88 in Nord-Trøndelag IR on the local level was lower than on the national. In 2006-09 however IRR went up with the factor 1, 45 in men in the age 0 to 29, indicating that cancer incidence rose in young men in Nord-Trøndelag comparing to whole Norway. In women similar tendency was presented. That supports suggestion that trend of cancer incidence has changed in at least one of the contaminated areas of Norway. IRR obtained indicate that we cannot reject hypothesis of increasing incidence in young people (aged 0-29) living in Nord-Trøndelag. So for some reason young (0-29) women and men in Nord-Trøndelag got relatively more cancer in the 90s and up to now comparing to the whole country. Exploring the pattern of cancer incidence further and analyzing IRR in different geographical areas of Nord- Trøndelag we can see that in the group 1 and 2 IRR rose in young men.

So far we can state that pattern of cancer incidence has changed over time in some (but not all) of the contaminated regions of Norway. We cannot claim however that this must be attributed to the Chernobyl disaster. Nevertheless numbers obtained help us generate hypothesis that can be used in further investigations. In my opinion it is hardly possible that internal and external dose from Chernobyl disaster alone can cause any discernible increase in cancer incidence in Norway. It can, however, serve as a trigger or «last straw» in the range of the carcinogenic agents posed on the population. The fact that there were dissimilarities in IR dynamics between two most polluted areas of Oppland and Nord-Trøndelag makes

us look closer to the differences between those 2 populations. As it was stated before Sámi reindeer herders were the most vulnerable group because of their dependency on local food production and high reindeer meet consumption. Hence higher intake of local food that takes place in Nord-Trøndelag is consistent with increased IRR over time there.

It should be noted however that this study has serious limitations. Those involve small population sample size, absence of adjustment for possible confounders, such as lifestyle factors (smoking habits, diet etc.), level of air pollution (can differ in the cities and on the countryside) or presence of other chemical carcinogens in the environment. Another limitation is that IRR are calculated only for 2 time periods, which are divided by 15 years gap. Further studies could include analysis of the dynamics of the IRR in the period between 1986 and 2000. Moreover population migration processes are not taken in the consideration.

All in all, in my opinion, present study has accomplished its goal despite all mentioned limitations. It has generated hypothesis that fallout after Chernobyl disaster has affected cancer incidence in one of the most polluted areas of Norway (Nord-Trøndelag). This, however, is a tentative analysis and further investigation should be conducted to confirm or reject that.

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Appendix

Figure 5. Cancer incidence rates in women in the age groups 00-09, 10-19 and 20-29 in timeperiods 1966-85(1); 1986-90(2); 1991-95(3); 1996-2000(4); 2001-2005(5);2006-2009(6). Whole Norway.

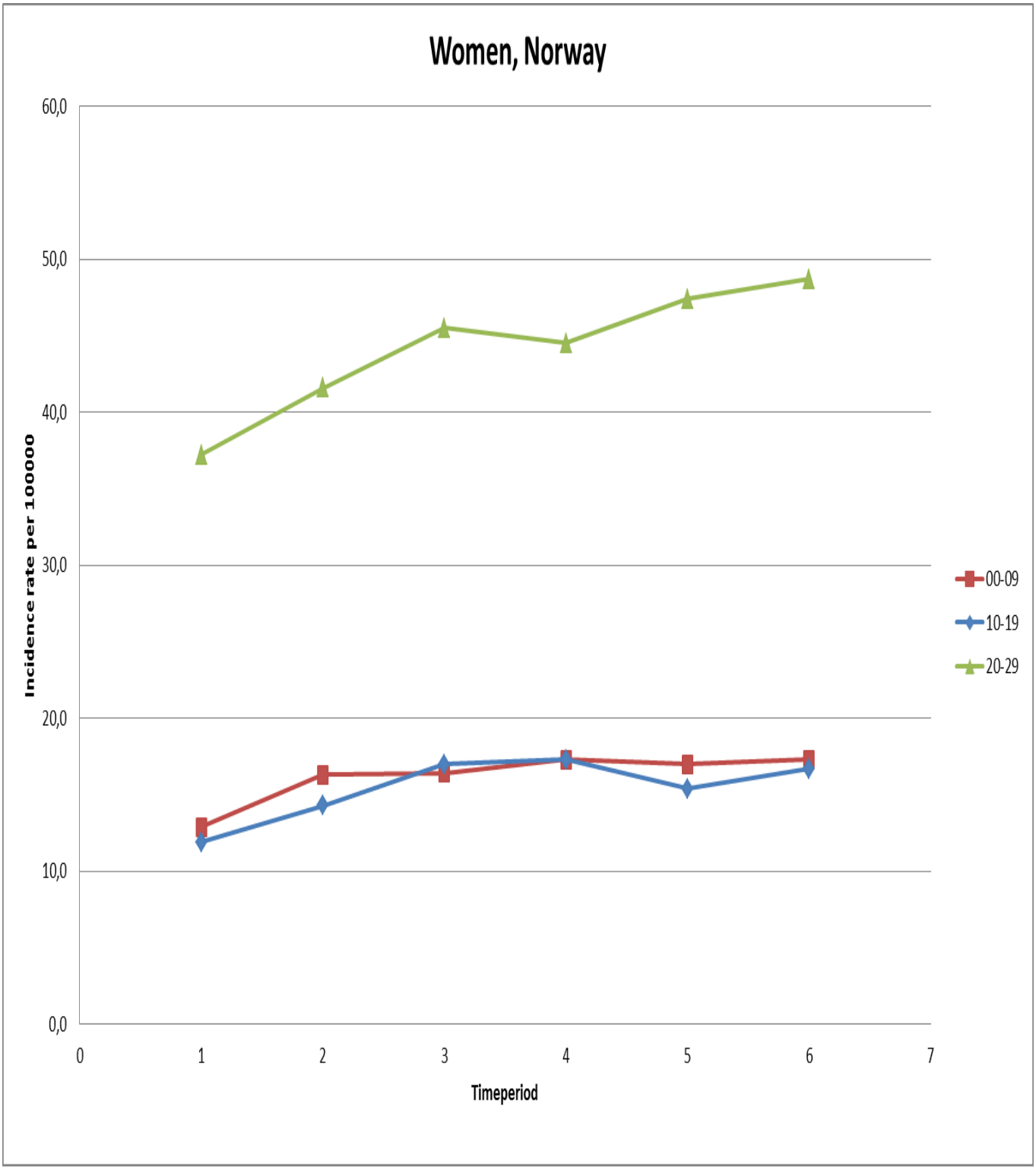

Figure 6. Cancer incidence rates in men in the age groups 00-09, 10-19 and 20-29 in timeperiods 1966-85(1); 1986-90(2); 1991-95(3); 1996-2000(4); 2001-2005(5); 2006-2009(6). Whole Norway

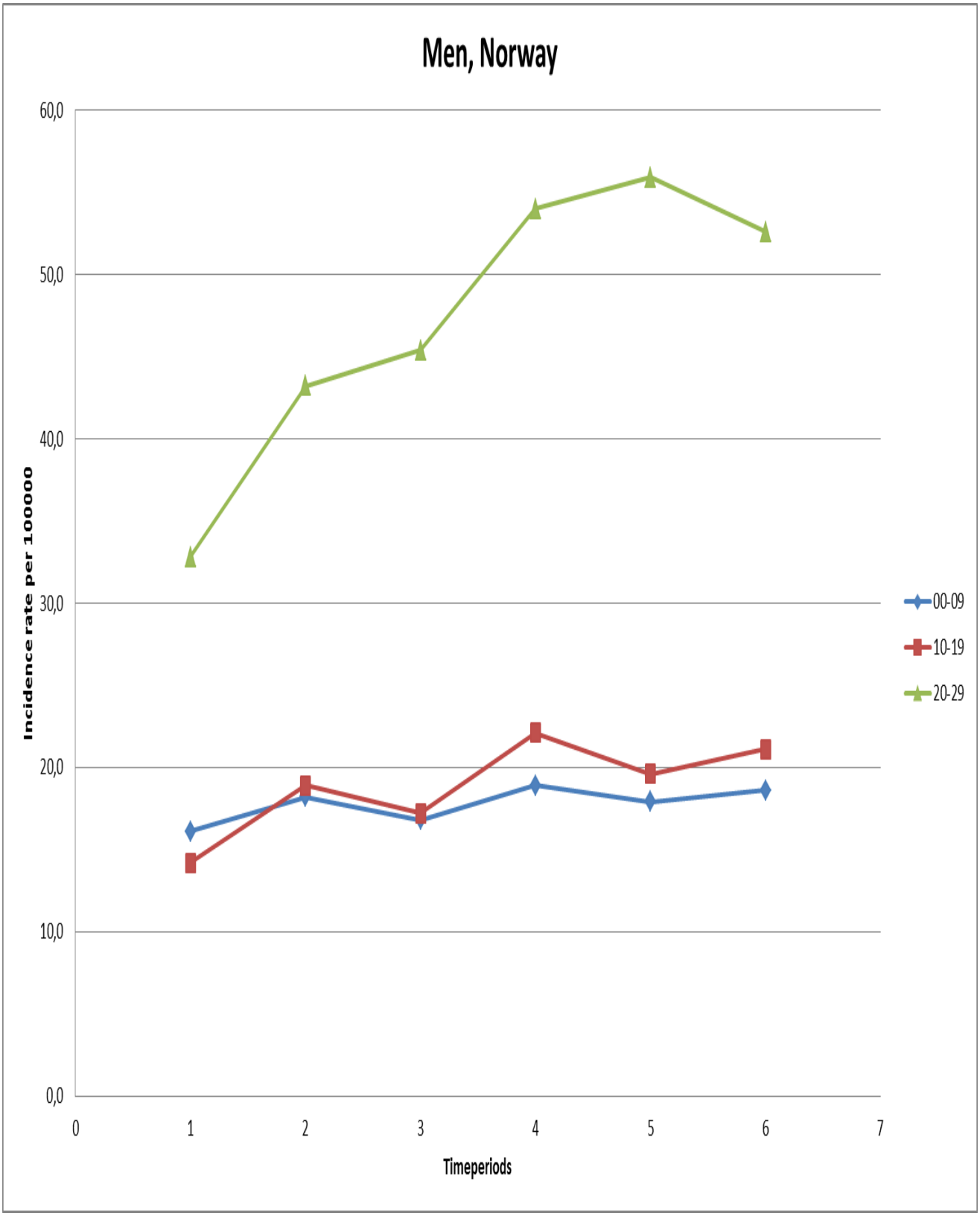

Figure 7. Cancer incidence rates in men in the age groups 00-09, 10-19 and 20-29 in timeperiods 1966-85(1); 1986-90(2); 1991-95(3); 1996-2000(4); 2001-2005(5); 2006-2009(6). Oppland.

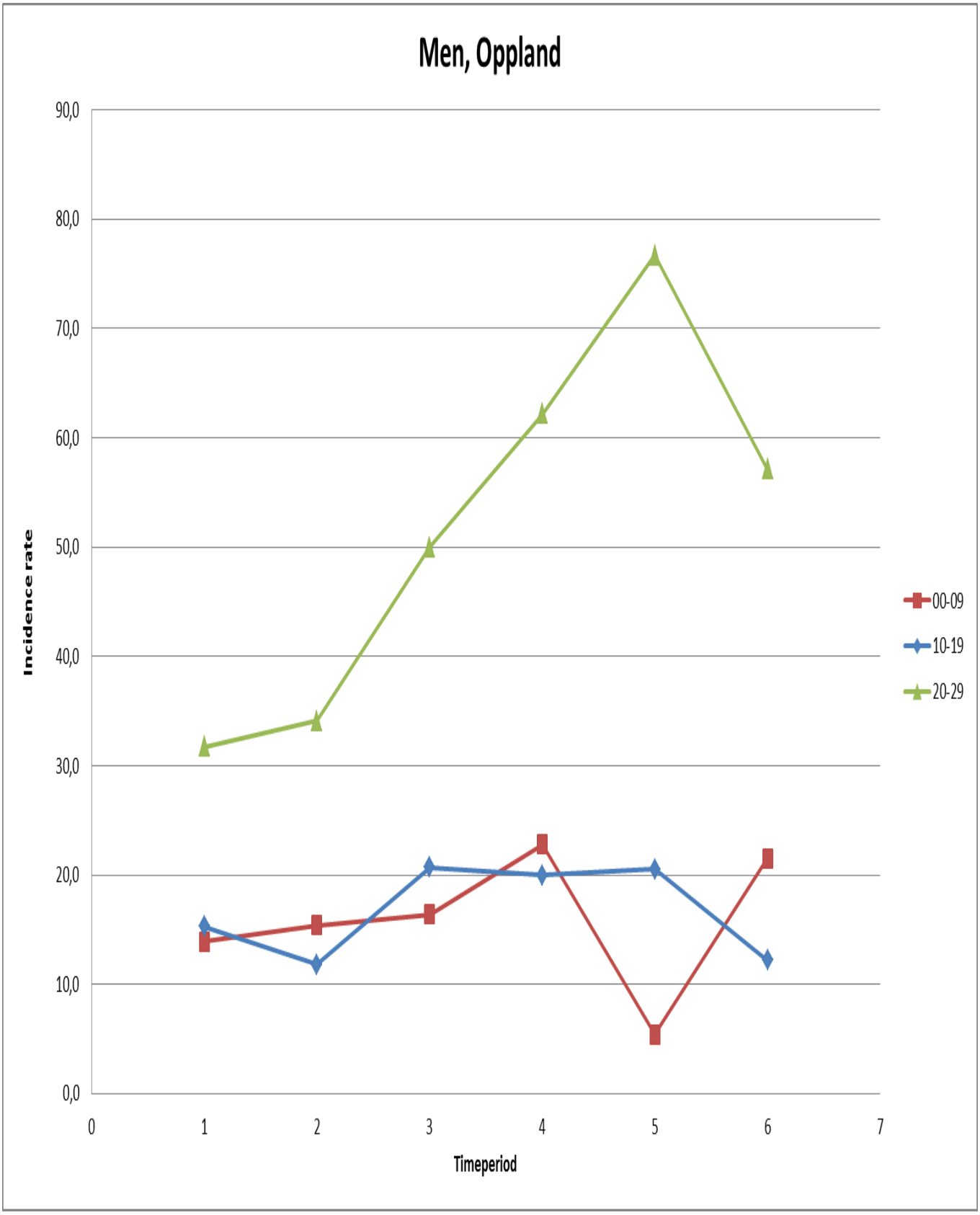

Figure 8. Cancer incidence rates in women in the age groups 00-09, 10-19 and 20-29 in timeperiods 1966-85(1); 1986-90(2); 1991-95(3); 1996-2000(4); 2001-2005(5); 2006-2009(6). Oppland.

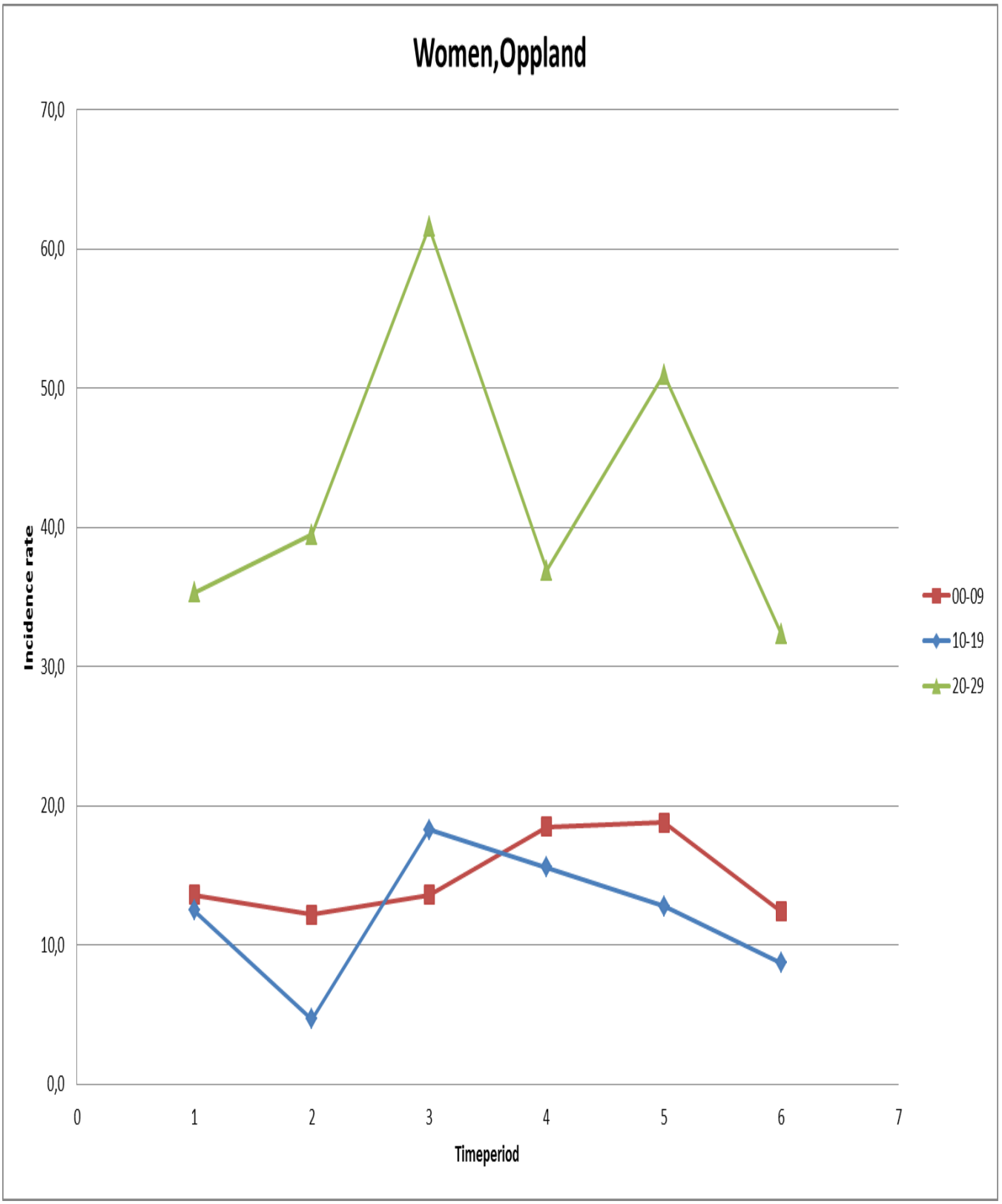

Figure 9. Cancer incidence rates in men in the age groups 00-09, 10-19 and 20-29 in timeperiods 1966-85(1); 1986-90(2); 1991-95(3); 1996-2000(4); 2001-2005(5); 2006-2009(6). Nord-Trøndelag.

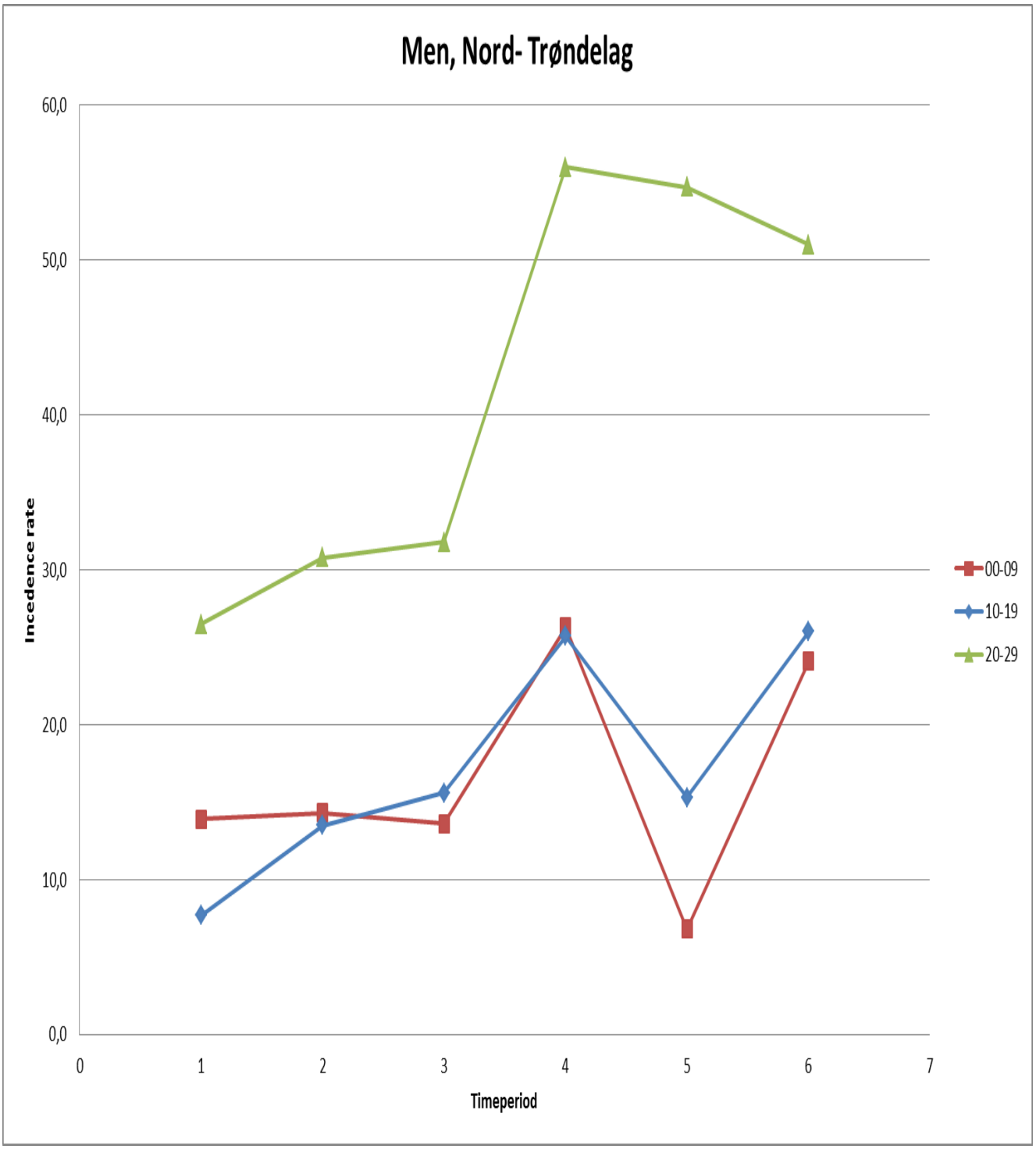

Figure 10. Cancer incidence rates in women in the age groups 00-09, 10-19 and 20-29 in timeperiods 1966-85(1); 1986-90(2); 1991-95(3); 1996-2000(4); 2001-2005(5); 2006-2009(6). Nord-Trøndelag.

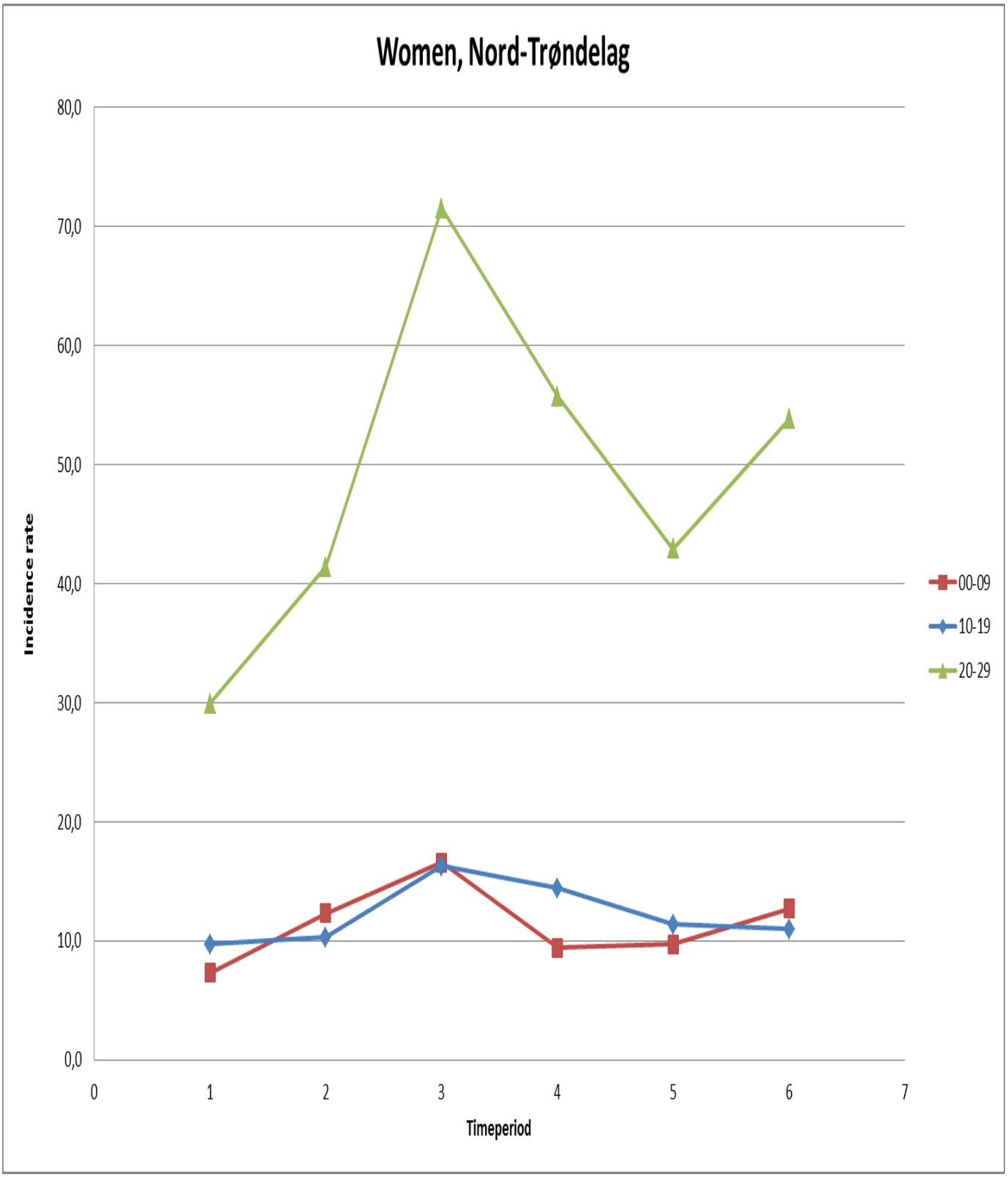

Table 1. Radionuclide inventory in Unit 4 at time of the accident on 26 April 1986.

Radionuclide	*Half-life*	*Activity (PBq)*			
		1986 estimates [I2] a	*Estimates by [B1, I2]*	*Estimates by [S1]*	*Estimates by [B2, B3, B4] b*
3H	12.3 a			1.4 *d*	
14C	5 730 a			0.1 *d*	
85Kr	10.72 a	33	33	28	
89Sr	50.5 d	2 000	2 330	3 960	220
90Sr	29.12 a	200	200	230	
95Zr	64.0 d	4 400	4 810	5 850	
95Nb	35 d			5 660	
99Mo	2.75 d	4 800	5 550	6 110	
103Ru	39.3 d	4 100	4 810	3 770	850
106Ru	368 d	2 100	2 070	860	
110mAg	250 d			1.3	
125Sb	2.77 a			15	
129mTe	33.6 d			1 040	
132Te	3.26 d	320	2 700	4 480	4 200 *f*
129I	15 700 000 a			0.000081 *d*	
131I	8.04 d	1 300	3 180	3 080	3 200 *f*
132I	2.3 h			4 480	4 200 *f*
133I	20.8 h			6 700	4 800 *f*
134I	52.6 min				2 050 *f*
135 I	6.61 h				2 900 *f*

133Xe	5.25 d	1 700	6 290	6 510	
134Cs	2.06 a	190	190	170	150
136Cs	13.1 d			110 *e*	
137Cs	30.0 a	290	280	260	260
138Cs	32.2 min			6 550	
140Ba	12.7 d	2 900	4 810	6 070	
140La	40.3 h			6 070	
141Ce	32.5 d	4 400	5 550	5 550	
144Ce	284 d	3 200	3 260	3 920	3 920
147Nd	11.0 d			2 160	
154Eu	8.6 a			14	
235U	704 000 000 a			0.000096 *d*	
236U	23 400 000 a			0.0085 *d*	
238U	4 470 000 000 a			0.0023 *d*	
237Np	2 140 000 a			0.00026	
239Np	2.36 d	140	49 600 *c*	58,100	58 100
236Pu	2.86 a			0.0001	
238Pu	87.74 a	1	1.0	1.3	0.93
239Pu	24065 a	0.8	0.85	0.95	0.96
240Pu	6537 a	1	1.2	1.5	1.5
241Pu	14.4 a	170	170	180	190
242Pu	376 000 a		0.0025	0.0029	0.0021
241Am	432 a			0.17	0.14
243Am	7 380 a			0.0097	0.0056
242Cm	163 d	26	15 *c*	43	31
244Cm	18.1 a			0.43	0.18

Table 2. Current estimate of radionuclide releases during the Chernobyl accident (modif. from 95De)

Core inventory on 26 April 1986			**Total release during the accident**	
Nuclide	**Half-life**	**Activity (PBq)**	**Percent of inventory**	**Activity (PBq)**
33Xe	5.3 d	6 500	100	6500
131I	**8.0 d**	**3 200**	**50 - 60**	**~1760**
134Cs	**2.0 y**	**180**	**20 - 40**	**~54**
137Cs	**30.0 y**	**280**	**20 - 40**	**~85**
132Te	78.0 h	2 700	25 - 60	~1150
89Sr	52.0 d	2 300	4 - 6	~115
90Sr	28.0 y	200	4 - 6	~10
140Ba	12.8 d	4 800	4 - 6	~240
95Zr	1.4 h	5 600	3.5	196
99Mo	67.0 h	4 800	>3.5	>168
103Ru	39.6 d	4 800	>3.5	>168
106Ru	1.0 y	2 100	>3.5	>73
141Ce	33.0 d	5 600	3.5	196
144Ce	285.0 d	3 300	3.5	~116
239Np	2.4 d	27 000	3.5	~95
238Pu	86.0 y	1	3.5	0.035
239Pu	24 400.0 y	0.85	3.5	0.03
240Pu	6 580.0 y	1.2	3.5	0.042
241Pu	13.2 y	170	3.5	~6
242Cm	163.0 d	26	3.5	~0.9

(From “Chernobyl: Assessment of Radiological and Health Impact 2002 Update of Chernobyl: Ten Years On” http://www.oecd-nea.org/rp/chernobyl/c02.html)

Table 3 .Cancer incidence rates, Norway.

Men	Time-period 1 1966-85	Time-Period 2 1986-90	Time-period 2 1991-95	Time-period 3 1996-00	Time-Period 4 2001-05	Time-Period 5 2006-09
00-09	16,1	18,2	16,8	18,9	17,9	18,6
10-19	14,2	18,9	17,2	22,1	19,6	21,1
20-29	32,8	43,2	45,4	54,0	55,9	52,6
	63,1					92,3
30-39	60,5	67,3	73,7	76,7	81,7	91,9
40-49	142,0	153,5	174,5	169,3	170,9	174,4
50-59	403,6	484,9	485,9	513,1	570,8	622,9
	606,1					889,2
60-69	1018,1	1254,1	1384,6	1542,7	1594,0	1731,2
70-79	1983,2	2362,2	2614,7	2779,0	2960,2	3176,3
80+	2674,9	3242,4	3485,6	3516,8	3876,0	3840,5
	5676,2					8748,0
Alle	344,4	439,1	478,2	507,5	549,4	601,2
Just.	227,0	270,9	293,2	315,2	333,8	357,0
Women	Time-period 1 1966-85	Time-Period 2 1986-90	Time-period 2 1991-95	Time-period 3 1996-00	Time-Period 4 2001-05	Time-Period 5 2006-09
00-09	12,9	16,3	16,4	17,3	17,0	17,3
10-19	11,9	14,3	17,0	17,3	15,4	16,7

20-29	37,2	41,6	45,5	44,5	47,4	48,7
	62,0					82,7
30-39	116,6	124,7	129,8	120,3	127,2	132,4
40-49	291,9	295,0	320,8	328,6	328,3	326,7
50-59	479,8	547,5	588,9	666,2	720,8	699,3
	888,3					1158,4
60-69	732,9	873,2	963,5	1072,8	1170,3	1190,8
70-79	1117,8	1289,7	1377,5	1472,2	1627,2	1725,7
80+	1498,9	1688,5	1727,4	1826,9	1983,7	2110,0
	3349,6					5026,5
Alle	321,9	394,9	425,4	459,0	499,1	519,4
Just.	201,7	227,6	245,3	264,0	281,6	287,3

Table 4. Incidence rates, Nord-Trøndelag

Men	Time-period 1 1966-85	Time-Period 2 1986-90	Time-period 2 1991-95	Time-period 3 1996-00	Time-Period 4 2001-05	Time-Period 5 2006-09
00-09	13,9	14,3	13,6	26,3	6,8	24,1
10-19	7,7	13,5	15,6	25,7	15,3	26,0
20-29	26,5	30,8	31,8	56,0	54,7	51,0
	48,1					101,1
30-39	69,6	83,4	79,2	76,9	123,7	91,0
40-49	133,5	139,4	191,0	171,1	163,3	141,9
50-59	334,1	379,3	388,0	472,0	547,5	575,1
	537,2					808,0
60-69	859,3	1155,5	1241,3	1326,8	1389,1	1541,7

70-79	1751,5	2237,9	2478,3	2323,4	2859,2	2870,5
80+	2352,2	3045,0	3269,1	3361,8	3956,7	3239,8
	4963,0					7652,0
Alle	312,9	430,2	471,4	492,8	579,9	595,7
Just.	196,1	245,1	269,3	283,6	315,7	321,2
Women	Time-period 1 1966-85	Time-Period 2 1986-90	Time-period 2 1991-95	Time-period 3 1996-00	Time-Period 4 2001-05	Time-Period 5 2006-09
00-09	7,3	12,3	16,6	9,4	9,7	12,7
10-19	9,7	10,3	16,3	14,4	11,4	11,0
20-29	29,9	41,4	71,5	55,7	42,9	53,8
	46,9					77,5
30-39	82,1	103,2	125,3	103,8	101,5	118,5
40-49	261,9	285,4	242,6	266,6	270,0	274,1
50-59	422,5	565,4	527,8	522,2	654,7	724,0
	766,5					1116,6
60-69	686,8	766,6	927,7	851,7	1095,8	1228,6
70-79	1104,4	1145,0	1384,4	1391,4	1591,2	1717,0
80+	1471,2	1611,8	1811,1	1776,5	1864,4	2063,7
	3262,4					5009,3
Alle	291,3	360,7	416,6	416,8	482,4	546,1
Just.	181,9	209,4	232,9	221,7	254,8	284,6

Table 5. Incidence rates, Oppland

Menn	Time-	Time-	Time-	Time-	Time-	Time-

	period 1 1966-85	Period 2 1986-90	period 2 1991-95	period 3 1996-00	Period 4 2001-05	Period 5 2006-09
00-09	13,9	15,4	16,4	22,8	5,4	21,5
10-19	15,3	11,8	20,7	20,0	20,5	12,2
20-29	31,7	34,1	50,0	62,2	76,7	57,1
Sum	60,9					90,8
30-39	57,4	63,6	69,3	65,1	96,7	78,9
40-49	124,9	128,3	166,2	167,2	163,4	194,1
50-59	325,8	471,6	428,1	470,4	526,4	599,8
Sum	508,1					872,8
60-69	797,8	1041,5	1180,7	1402,5	1503,4	1634,9
70-79	1654,0	2118,4	2222,7	2383,2	2776,1	2859,3
80+	2266,7	2890,3	3250,2	3259,8	3632,2	3328,6
Sum	4718,5					7822,8
Alle	330,3	452,3	496,1	541,4	614,0	659,8
Just.	187,9	236,9	259,9	285,4	318,0	334,8
Kvinner	Time- period 1 1966-85	Time- Period 2 1986-90	Time- period 2 1991-95	Time- period 3 1996-00	Time- Period 4 2001-05	Time- Period 5 2006-09
00-09	13,6	12,2	13,6	18,5	18,8	12,4
10-19	12,5	4,7	18,3	15,6	12,8	8,7
20-29	35,3	39,5	61,6	36,9	51,0	32,3
Sum	61,4					53,4

30-39	108,5	117,7	124,1	109,4	134,5	134,8
40-49	283,2	262,6	256,6	251,5	332,9	323,8
50-59	427,0	517,0	543,5	659,8	669,2	698,2
Sum	818,7					1156,8
60-69	637,3	878,3	878,6	929,4	1163,5	1140,3
70-79	1024,5	1126,2	1225,9	1314,2	1457,8	1593,4
80+	1325,1	1535,9	1556,7	1730,0	1865,9	1807,5
Sum	2986,9					4541,2
Alle	303,3	392,0	418,5	461,8	531,2	551,0
Just.	183,3	209,4	223,2	235,5	272,3	271,6

Table 6. Cancer incidence between 1966 and 2009, Norway

Menn	66&85	86&90	91&95	96&00	01&05	06&09
00-09	995	246	247	295	275	227
10-19	916	291	239	306	297	274
20-29	2011	724	776	855	810	630
	3922	1261	1262	1456	1382	1131
1/I	0.00025					0.00088
30-39	3084	1076	1204	1315	1445	1278
40-49	6286	2111	2726	2676	2786	2439
50-59	18396	4641	5019	6756	8582	7683
	27766	7828	8949	10747	12813	11400
1/I	0.000036					0.000088
60-69	38971	12465	12411	13046	14830	16338
70-79	44831	15909	18623	19635	19664	16551
80+	21241	8303	9867	10967	13682	11740
	105043	36677	40901	43648	48176	44629
1/I	0.0000095					0.0000224
Kvinner	66&85	86&90	91&95	96&00	01&05	06&09
00-09	758	209	228	256	248	202
10-19	732	211	225	228	222	205
20-29	2156	661	743	683	671	565
	3646	1081	1196	1167	1141	972
1/I	0.00027					0.001

30-39	5653	1887	2023	1966	2171	1774
40-49	12646	3858	4753	4987	5167	4337
50-59	22314	5285	6059	8537	10471	8354
	40613	11030	12835	15490	17809	14465
1/I	0.000025					0.00007
60-69	31551	9620	9427	9761	11377	11359
70-79	33937	11816	13227	13662	13583	10864
80+	19997	8530	9796	11477	13722	12042
	85485	29966	32450	34900	38682	34265
1/I	0.000012					0.00003
Sum:	129744	42077	46481	51557	57632	49702

Table 7. Cancer incidence (I), Nord-Trøndelag

Menn	66&85	86&90	91&95	96&00	01&05	06&09
00-09	28	6	6	12	3	8
10-19	17	7	7	11	7	10
20-29	47	15	16	24	20	15
	92	28	29	47	30	33
1 / I	0.01					0.03
30-39	102	38	35	34	54	29
40-49	175	56	87	77	73	53
50-59	466	106	118	182	241	206
	743	200	240	293	368	288
1 / I	0.0013					0.0035
60-69	1050	362	345	339	397	442
70-79	1331	500	566	530	606	472
80+	672	282	329	358	453	321
	3053	1144	1240	1227	1456	1235
1 / I	0.00033					0.00081
Kvinner	66&85	86&90	91&95	96&00	01&05	06&09
00-09	14	5	7	4	4	4
10-19	20	5	7	6	5	4
20-29	47	18	32	22	15	15
	81	28	46	32	24	23
1 / I	0.012346					0.044
30-39	114	44	52	43	43	37
40-49	328	108	103	113	114	96
50-59	570	156	157	193	274	246
	1012	308	312	349	431	379
1 / I	0.001					0.003
60-69	863	247	267	224	315	349
70-79	974	315	393	379	395	319
80+	590	239	304	338	381	350

	2427	801	964	941	1091	1018

Table 8. Cancer incidence (I), Oppland

Men	66&85	86&90	91&95	96&00	01&05	06&09
00-09	36	8	9	13	3	9
10-19	44	8	12	11	12	6
20-29	77	23	35	38	40	23
Sum	157	39	56	62	55	38
1 / I	0.0064					0.026
30-39	122	41	44	42	63	37
40-49	253	75	109	109	106	104
50-59	704	210	198	268	336	308
Sum	1079	326	351	419	505	449
1 / I	0.0009					0.0022
60-69	1513	519	523	565	643	682
70-79	2068	741	820	869	921	727
80+	1066	431	507	538	666	516
Sum	4647	1691	1850	1972	2230	1925
1 / I	0.0002					0.0005
Sum:	5883	2056	2257	2453	2790	2412
Women	66&85	86&90	91&95	96&00	01&05	06&09
00-09	33	6	7	10	10	5
10-19	34	3	10	8	7	4
20-29	81	24	39	21	25	12
Sum	148	33	56	39	42	21
1 / I	0.007					0.05
30-39	227	73	76	67	84	62
40-49	560	152	164	159	211	168
50-59	911	229	254	376	421	349
Sum	1698	454	494	602	716	579
1 / I	0.0006					0.002
60-69	1248	463	412	393	522	494
70-79	1440	484	557	593	588	470
80+	811	356	405	497	589	478
Sum	3499	1303	1374	1483	1699	1442
1 / I	0.003					0.0007
Sum:	5345	1790	1924	2124	2457	2042