# Epidemiological study into cancers in Gibraltar

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## Data sheet

Title: Epidemiological study into cancers in Gibraltar

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Abstract: *This environmental epidemiological study assess the relative cancer risk and the role of environmental factors herein in Gibraltar. The study conducted a weight-of-evidence analysis on credible and available environmental data relative to the reported cancer registry data. The study found that the cancer incidence rates are within the normal ranges of the rest of the EU. The levels of carcinogens in Gibraltar ambient air are within the normal ranges of what is found in the air in cities in the rest EU and within the guideline values of the EU.*

Keywords: Epidemiology, Cancer, Air, PAH, Nickel, Arsenic, Environmental compartments, Modelling,

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## Contents

# 1 Executive summary

The global burden of cancer is increasing, especially in the developed world. Globally one in two men and one in three women will be diagnosed with cancer during their life time, for one of three of these women the diagnosis will be breast cancer. Annually, around 10 million people worldwide will be diagnosed with cancer and a total of 28 million people are currently cancer patients. The World Health Organization (WHO) estimates that the worldwide cancer rates are set to increase by as much as 50 % within a decade unless further preventive measures are put into practice. Preventive measures could include reduction in the involuntary exposure to environmental contaminants. According to the European Environment and Health Action Plan 2004–2010 it is estimated that each year thousands of city dwellers across the EU die prematurely due to air pollution and that one-sixth of the total burden of death and disease in European children can be attributed to environmental factors. The role of environmental parameters in the societal cancer burden is currently estimated to be approx. 5 %. However, some 40 % of the total cancer burden is still unaccounted for – so the contribution could be larger than 5 %. Cancer aetiology is complex, multi-causal, there can be up to decades between exposures and effects and the actual diagnosis. The cancer incidence rate increases exponentially with age.

The total cancer incidence rate in Gibraltar is within the normal ranges of other European countries. Gibraltar is not a high-risk community for cancer. Breast cancer is however in the upper centiles among EU countries and is a priority cancer type. Moreover, measured exposure concentrations of carcinogens in the air pollution exposures in Gibraltar are within the normal ranges of EU cities. Exposure to carcinogenic compounds is always associated with a cancer risk, typically expressed as a 1:10,000 person risk, since these carcinogens are characterized by their lack of thresholds, i.e. any exposure, in principle one molecule, may cause cancer. Measured concentrations of the carcinogens PAH, arsenic and nickel in Gibraltar ambient air reach levels that may increase the 1:10,000 person risk in Gibraltar.

Modeling of industry emissions in the Bay Area and diffuse emissions from adjacent Spanish municipalities shows that the contribution to ambient air in Gibraltar from industrial sources exceeds that from the diffuse sources. There is, moreover, a decrease in annual mean air concentrations from industrial emissions between years 2005 and 2008. Modeling reveals that chromium in the Gibraltar air is potentially close to the 1:10,000 risk value. No measurements have been made on chromium.

Ambient air PAH, arsenic, nickel, and chromium are priority pollutants. The primary emitters of carcinogenic air pollutants are the nearby industries in Spain (CEPSA, Acerinox, Interquisa, Petresa, Lubricantes del Sur, Edar de la Linea de la Concepcion). Carcinogenic pollutants contributions from CEPSA flaring, ship traffic in the Bay and Straits, local road traffic and local diesel generators are currently un-quantified due to lacking emission data on carcinogens.

# 2 Introduction

## 2.1 Background

The Government of Gibraltar and the Gibraltarian public are interested in investigating the cancer incidence rates in Gibraltar and in comparing these to expected cancer incidence rates, to evaluate if environmental factors in Gibraltar could explain deviations in the incidence rates relative to other comparable areas. The objectives of this study are to:

- To establish whether Gibraltar is a high-risk community for cancer, due to its location within the vicinity of potential sources of environmental exposure or health hazards, which potentially result in unacceptable levels of exposure to contaminants or pollutants.
- To establish whether there actually exists a greater than expected incidence of cancer in Gibraltar.

More specifically the following hypotheses were tested:

- Is there a correlation and possible causation between observed environmental pollutants and increased incidence rates of cancer?
- Is there an increased rate for a certain type of cancer that could be linked to environmental pollutants?
- If there are environmental cancer risks due to pollutants are these related to specific activities in the area?
- What is the pathway for exposure, e.g. drinking water or air pollution?

The first paragraph of the Environment Charter of Gibraltar states; '*To recognise that all people need a healthy living environment for their well-being and livelihood and that all can help to conserve and sustain it*'. This is an important statement which relates to this epidemiological study as it links the human and environmental health status. Our surrounding environment certainly does impact on human health (EU, 2003).

This prompts concerns among the public and warrants proportional actions by the responsible governments to reduce risks. Environmental effects on human health are multifaceted and many are systemically embedded in wider environmental, socioeconomic and political systems. The diseases, such as cancer, associated with environmental epidemiology are often chronic and multi-causal. The expression of the disease is therefore both a cumulative reflection of genetics, lifestyle, age, and environmental exposures as well as many other potential stressors.

We have known since the early 1980s that cancers related to low chronic exposures to environmental contaminants often have a highly uncertain and non-linear dose-response shape. The Doll and Peto (1981) study for the WHO established that the environment contributes 4-6 % of the total cancer burden within a standard population.

There are very few comprehensive environmental cancer epidemiological studies conducted in the world on the general population, and also significant gaps in toxicological assessment and appreciation of the cancer risks of life-long exposures to multiple environmental and anthropogenic stressors. The study into cancers and the role of background environmental factors in Gibraltar is therefore both ambitious and highly relevant.

# 3 Methods

## 3.1 Etiological approach

Cancer development and survival are complex from a medical point of view and often systemic in nature, i.e. to some extent reflecting societal priorities. It is a function of heredity (genetics and parents exposures, epigenetic), chance and susceptibility (which mutations may survive and be malign), the persons lifestyle, time (there can be years between the cause and effect), the health care provided, etc., among others environmental factors. Cancer is per definition multi-causal and often displays delayed and non-linear responses, which needs to be reflected in the risk appraisal (Hanahan & Weinberg, 2000). Hence, ascribing causal relationships is often very difficult. Having said this we do know causing agents e.g. related to lifestyle (e.g. diet, alcohol, tobacco, exercise). In this study it is important to distinguish between why patients get sick and die from cancer and potential elevated cancer risks which are related to environmental factors. We will not perform retrospective causal investigations of disease patterns but we will focus on the prospective analyses and potential future risks. Moreover, we will not focus on the mortality rates as this would also require an assessment of the health care provided, which is outside the scope of the study.

In the analysis we will apply expert judgement in relation to the derived data and the results of the analysis, and weigh and evaluate the data and the exposure scenarios in a precautionary cumulative risk context relative to the identified study aims. We ascribe to the nine Bradford-Hill (1965) qualitative and quantitative criteria for causation; strength of association, consistency, dose–response, biologic plausibility, and temporality, specificity (coherence, analogy, and experimentation), in the weight-of-evidence analysis.

The design of the present study will follow the DPSEEA (Drivers, Pressures, State, Exposure, Health Effects, Actions) framework. In brief, the DPSEEA elements can be described as follows: Drivers (D) represent the societal mechanisms (policies, economics, etc); D facilitates the Pressures, (P) - being the structures/activities in this case e.g. refinery, traffic, agriculture, etc; P then causes a State, (S) – i.e. what can be observed, e.g. with regard to air quality; the S can then be defined more precisely in space and time in terms of Exposures, (E) - both measured, modelled and extrapolated; the exposure then causes Health Effects, (E) which are evident from the exposure toxicities and observed disease and cancer rates; the last step is then Actions, (A) - which is the policy response that, based on the analysis, seeks to inform adaptive management strategies and policies relative to any point of the D-P-S-E-E-A chain to achieve an effective and sustainable risk reduction. D and A represent societal and policy-based drivers and action plans, whereas mentioned the focus within this project is on the P; S; E; E aspects. Results from the risk assessment will be presented according to DPSEEA conceptual model and can form the basis for policy decision support (Briggs, 2008).

## 3.2 Environmental Compartments

We have compartmentalized the environment in Gibraltar. We focused on the quality of the environmental compartments to assess the level of exposure of carcinogenic contaminants they may represent. The environment in Gibraltar thus consists of the following environmental compartments, which are then further split up in potential exposure routes:

- Water (drinking water, sea water, bathing water).
- Soil (ground, beach, rock/geology).
- Air (atmospheric exposures).
- Miscellaneous (noise, electro magnetic fields).

The aim of the analysis of the environmental compartments in the DPSEEA model is to assess the State and subsequent Exposures based on the known Pressures.

The environmental exposures of interest in this study would have to be specific or elevated to Gibraltar, in order for them to explain any potential deviations in the cancer incidence rate pattern found in the rest of Europe. Hence, we first test if the general quality criteria set out in EU directives are met for each compartment, and then supplement these with additional relevant cancer risk parameters.

There are also other more indirect environmental exposures e.g. via food, UV exposure etc. After discussing these indirect exposures, notably food intake, with the authorities on this matter in Gibraltar (Environmental Agency) it was concluded that the food intake is not significantly different in origin, types and amounts, from the foodstuff consumed in many other places in the UK, Spain and the rest of the EU. Food does therefore not represent a unique exposure route to Gibraltarians and is thus not further analysed in the present study as a specific cancer risk in Gibraltar.

UV radiation and protection hereof is an important cancer risk, however, this is not a specific risk parameter to Gibraltar. The amount of UV radiation is governed by processes in the upper atmosphere and therefore covers large areas and is typically a function of latitude and longitude and hence not specific to Gibraltar. Moreover, genetic and lifestyle related risk factors (e.g. smoking, alcohol, diet, exercise) certainly play a significant role in the cancer risk, these parameters are beyond the scope of this study and are therefore not included. Analyses of indoor air quality and workplace safety are also beyond the scope of this work and not included.

We know from other studies elsewhere that the typical primary exposure route of carcinogens to humans in urban environments is the ambient air quality (Danaei et al. 2005), hence this compartment will, all other factors being equal receive the most detailed scrutiny. In analysing these parameters we will use the EU Technical Guidance Document (EU TGD, 2003) as the reference point for the complete analysis of point and diffuse environmental exposures to humans and the potential risks associated. We also make use high quality reliable emissions data collected and reported on by national or international authorities.

The existing wind modelling and source analysis will be assessed in conjunction with realistic worst-case exposure models, as refinement of the Tier 1 conservative exposure analysis detailed in the EU Technical Guidance Document for risk assessment. The relative carcinogenicity of the pollutants will be determined by cross-checking EU, WHO and U.S. EPA data sources (ENCR; IARC and IRIS).

During this search, safe reference doses (RfDs) and reference concentrations (RfCs) or acceptable exposure levels will be established. We will compile a state-of-the-science matrix with the relevant pollutants, based on the emissions and exposure data, displaying their respective ranges of carcinogenicities and toxicities. We will moreover, use the available measured and modelled environmental exposure data and compare these to the RfD/RfCs.

The further methodological details for the analysis of each environmental compartment are presented in the analysis and result section for each compartment.

## 3.3 Cancer Registry Analysis

Data from the cancer registry in Gibraltar (1999-2009) is used for the analysis. We will focus on the cancer incidence rates as these are a more direct reflection of the potential exposure risk characteristics, than for example mortality.

Within the DPSEEA model, the aim of the analysis of the Gibraltar cancer registry is to assess the State of the cancer incidence rates relative to the rest of the EU and based on the State to assess the potential Health Effects, which can then in the further analysis be linked to the Exposures and address the potential Pressures.

In order to determine if Gibraltar represents a high cancer risk area we need to compare the cancer incidence rates with otherwise comparable areas. This requires reliable and high quality comparable cancer incidence rate data from other regions – typically countries as maintenance of cancer incidence registry are resource intensive. In this comparative analysis we focus on the incidence rate the entire Gibraltar community experiences.

The key determinant of cancer incidence is age, as the risk of cancer increases exponentially with increasing age. To compare the incidence of cancer between countries, the summary rates should be independent of age. A common way to take into account the age structure of a population is to standardise incidence rates for age using an external (standard) population, in this case the European standard population. The age-standardised rate is a summary of the individual age-specific rates using an external population. This is the incidence that would be observed if the population had the age structure of the standard population, and corresponds to the crude incidence rate (*the rate at which new cases occur in a population during a specific period)* in the standard population. The age-standardised incidence rate is expressed, as is the crude incidence rate, as the number of new cases per 100 000 person-years. The use of this standard population allows international comparison and evaluation of changes in incidence by comparing them to rates published. It should be stressed that the objective of age standardisation is essentially to establish rates for comparison purposes (Boinol and Heanue, 2010).

The difficulties associated with this standardisation are discussed in paragraph 3.3.1 below.

The Gibraltar cancer registry incidence data is used to compute the EU age-standardized incidence rates (EASR) for international comparison for the major cancer types in total and for both sexes:

- Total incidence rate.
- Lung cancer.
- Bladder cancer.
- Colon rectum cancer.
- Pancreas cancer.

For females only:

- Breast cancer.
- Corpus uteri cancer.

For males only:

- Prostate cancer.

These cancer types were chosen as they alone represent the major cancer types in the EU and in Gibraltar (> 50 % of all cases). Other and less prevalent cancer types are very variable due to the very low incidence rates further complicating comparative analysis. As the mortality rate and incidence rate in Pancreas cancer within the EU are very similar we have also included a comparative analysis here too.

We know from GHA that the cancer registry prior to 2005 is under represented as the source data for the radiologically diagnosed cancers e.g. lung cancer, brain, bones, etc. are unavailable. Hence, the cancer registry is more robust and reliable for the years 2005-2009 for these types and for the total.

### 3.3.1 Statistical analysis

It is problematic to work with small populations and subsequent small cancer numbers when comparing the incidence rates to larger populations (i.e. comparing Gibraltar's some 30,000 inhabitants with the EU population that is more than 10 mill. times higher). This, results in a bias in the variation each registered cancer incidence contributes to the total variability. Thus the Gibraltar cancer incidence rates are more variable over time than the cancer incidence rates of the countries they are compared to, despite the standardization. This inherent bias is not reducible in normal univariate and multivariate statistical analysis, hence a direct traditional null hypothesis or Analysis Of Variance (ANOVA) quantitative significance testing is not appropriate, rather a weight-of-evidence multiple comparative analysis is in place.

When selecting countries to compare the EASR incidence rate with we chose to present the most recent high quality data that cover the same time period as the Gibraltar data, primarily post 2005. Hence, we used the European Cancer Observatory (ECO) under the International Agency for Research on Cancer (IARC), WHO and funded by the EU Commission. Herein we retrieved the most recent EASR incidence rates for all 27 EU countries as well as the EU-27 mean for the year 2008. We chose the ECO database as it represents the same source data as the Globocan database but is standardized to the European age structure rather than the global, and it is more comprehensive in terms of covering all European countries.

We compared these data with the Gibraltar mean incidence rates ± standard deviation for the 1999-2005, and 2005-2009 (for total cancer and lung cancer). As mentioned the incidence variance is relatively large in the Gibraltar data compared to all other countries due to the small numbers, which impairs the comparison. The average percent change in total cancer incidence rates over a 10 year period, for example, in Denmark ranges between 8 and 14 % for women and men, respectively. For the cancer types in this analysis the range is typically less than 10 %, with lung cancer among women as the exception where there was an increase of 27 % from 1998-2007. The Danish over all increase is thus roughly 1 % per year (Sundhedsstyrelsen (Natl. Board of Health, Denmark), 2009). Hence, one may, all other factors being equal,cautiously assume a variance of approximately 10 % for the incidence rates reported in the EU in 2008 to cover the period 1998-2008, when comparing the data to the Gibraltar mean values for 1999-2009.

As mentioned above the primary driver for differences within and between countries is the age structure of the population, hence this is a primary parameter to consider rather than for example geographic or historical connections. Moreover one needs to consider the quality of the cancer registry as some countries e.g. Spain model the incidence rate based on the cancer mortality what the cancer incidence rate then is, whereas the Gibraltar cancer database is a direct measure of the diagnosed cancers. In this respect and with respect to the age structure the cancer register in Gibraltar is may be more comparable to the Nordic cancer incidence rates than for example most other Mediterranean countries. In this analysis we therefore compare the Gibraltar data to all EU countries and the total EU-27, this allows us to assess if there is a greater cancer incidence risk in Gibraltar, for both sexes and in total for the primary cancer types, than expected when comparing to all the European countries and the EU27.

Additionally, the trends in the incidence rates in the Gibraltar cancer register will be presented and analysed.

# 4 Results

In this chapter we will present the results of the assessments described above.

## 4.1 Environmental Compartments

### 4.1.1 Water

The water compartment discusses and explores the potential exposures to the public in Gibraltar from drinking water; bathing water at the beach; and the marine environment.

**Drinking water**

**Background**

We had access to data from the Gibraltar Environmental Agency (2010a). In 2009AquaGib Ltd supplied a total of approx. 1,300,000 cubic metres of potable water to Gibraltar. The potable water consisted of approx. 94 % desalinated water and approx. 6 % well water. Since 2010, well water is no longer used for the supply of potable water. Potable water now consists of 100 % desalinated water. The Environmental Agency analytes are: colour; turbidity; odour; taste; pH; ammonium; conductivity; chlorides; coliform bacteria; E-coli bacteria, which is monitored weekly, as well as a number of chemicals that are monitored on a quarterly basis. We focused on data for the period between the first week of 2007 up until the first week of 2010. Monitoring and reporting was initiated December 2006.

**Results**

All of the weekly monitoring results were within the recommended limits for all the above parameters. The AquaGib quarterly samples are analysed for some 108 contaminants that could potentially be present in the water. Many of these are organic contaminants hereunder several pesticides and heavy metals. All the measured organic contaminants of potential concern with regards to cancer risks were below the limit of quantification (LoQ, ranging from 0.002 to 0.0075 μg/l), as well as any threshold of toxicological concern.

*PAH*

The total PAH concentration in the portable water sample from AquaGib is significantly below the guideline value for PAH (Benzo[a]pyrene) and at or below the levels found elsewhere in the world in uncontaminated groundwater (WHO, 2003).

*Carcinogenic heavy metals*

Arsenic is a very high priority contaminant as it is both a ubiquitous naturally occurring element, and at the same time a known carcinogen. The WHO guideline value was reduced in 2004, due to new epidemiological and toxicological concerns that had been raised, from 50 to 10 μg/l in potable water, and 10 μg/l in the drinking water supplies delivered at the tap. The arsenic concentration in the water is typically found at below 1 μg/l (Gibraltar Environmental Agency (2010a) - or a factor >10 less than the WHO guideline value (WHO, 2010). All other heavy metals investigated (nickel, lead, cadmium), were like arsenic, at a level significantly below the WHO guideline values (WHO, 2010).

#### *Other carcinogenic factors of potential concern*

*N*-Nitrosodimethylamine (NDMA) is a potential disinfection by-product in the production process of drinking water that includes a chlorination process, which has caused recent elevated concern with the WHO. It has been found to be a carcinogen with a suggested guideline value of 0.1 μg/l (WHO, 2008). The NDMA levels were measured in Gibraltar drinking water. The levels were below the detection limit of 0.001 μg/l, i.e. > 100 times below the WHO guideline value, thus suggesting that based on these measurements NDMA is not a specific cause for elevated cancer risks in Gibraltar (Aquagib, 2010).

Radon (Radium (Ra) 226 and 228). In many countries, drinking water is obtained from groundwater sources such as springs, wells and boreholes, these sources of water normally have higher concentrations of radium than surface water from rivers, lakes and streams, or indeed in desalinated seawater. In many countries, radon concentrations of 20 Bq/l – in some instances above 100 Bq/l – have been measured in individual water supplies. Since Gibraltar portable water consists of approx. 94 % desalinated seawater it is expected that the radon levels will be low, but should be assessed. The analysis showed that the $Ra^{226}$ and $Ra^{228}$ were below the detection limit of 0.005 and 0.02 Bq/l, respectively (Aquagib, 2010). The *WHO guidelines for drinking water quality* recommend repeated measurements to be implemented if radon in public drinking water supplies exceeds 100 Bq/l

These results suggest that Radon in the drinking water supply is not expected to be a potential cancer risk. Moreover, to date, epidemiological studies have not found an association between radon in drinking water and cancer of the digestive and other systems.

#### Conclusion

Based on the available data, there is no specific elevated cancer risk in the drinking water in Gibraltar, which is of high quality and in the upper centile of drinking water quality found elsewhere in the EU. The technique of desalination of seawater by reverse osmosis (RO) ensures a low contamination of the drinking water by most organic contaminants, which moreover are already significantly diluted in the ocean (Yoon and Lueptow, 2005).

### Bathing water

#### Background

The new EU Bathing Water Directive was adopted in 2006 (EU, 2006). The objective of the Directive is to protect the public health and ensure safe bathing waters. Experience of past years has shown that today the limiting factor for bathing water quality in the EU is microbiological pollution, either from waste water or other sources. Hence the emphasis for compliancy with the Directive is on total coliforms; E-coli; and faecal streptoccus. Elevated infection rates in the population may serve as a precursor and indicator of elevated cancer risks, therefore the bathing water must be safe from bacterial contamination. The capacity of pathogens in beach sand to infect beach users remains undemonstrated, and the real extent of their threat to public health is unknown. There is, therefore, no evidence to support the establishment of a guideline value for index organisms or pathogenic microorganisms in beach sand (WHO, 2010b);

The EU Directive sets mandatory standards and more conservative guideline standards for bacterial safety of bathing water (Table 3.1). *Intestinal Enterococci* will replace *Faecal streptoccus* as a measurement parameter.

Table 3.1 EU Bathing Water Directive standards.

| Bacteria | Mandatory value | Guideline value |
|---|---|---|
| Total Coliforms | 10,000/100ml | 500/100ml |
| E-Coli | 200/100ml | 100/100ml |
| Faecal streptoccus | None | 100/100ml |

**Results**

Gibraltar has six bathing areas, Camp Bay, Catalan Bay, Eastern Beach, Little Bay, Sandy Bay and Western Beach. These areas are monitored on a fortnightly basis during 15th April to 30th October each year. The Gibraltar beaches have always met the Mandatory Values and at least three of them have met the more stringent Guide Values consistently each year. Since 2003 all six sites have met the Guide Values (Gibraltar Environmental Agency (2010).

**Conclusions**

There is no specific elevated cancer risk due to poor bathing water quality at the six Gibraltar bathing areas compared with bathing areas in the rest of the EU, as the beaches comply with the EU Bathing Water Directive.

### Marine environment

**Background**

The European Union's Marine Strategy Framework Directive (EU MSFD, 2010) was adopted in June 2008 and is aimed at more effectively protecting the marine environment across Europe. It aims to achieve good environmental status of the EU's marine waters by 2020. The marine strategies to be developed by each Member State must contain a detailed assessment of the state of the environment, a definition of "good environmental status" at regional level and the establishment of clear environmental targets and monitoring programmes.

The MSFD is linked to the Water Framework Directive (EU WFD, 2010) via the River Basin Management plans. As part of the WFD is a commitment to the Directive on Priority Substances (DIR 2008/105/EC). Good chemical status, as is relevant as a first tier to the potential human exposure and causal link to cancer, is reached for a water body when compliance with all environmental quality standards for the priority substances and other pollutants listed in Annex I of the directive is achieved (EU WFD, 2010).

The aim of this factsheet is to focus on the potential direct and indirect human health risks contamination of the Bay of Gibraltar may cause and to examine if the contamination by priority substances is comparable to other sites along the southern shoreline of Spain.

#### Results

An assessment of the baseline macrobenthic ecology in proximity of the wastewater outfall concluded that no sewage related contamination was detected. The paucity of species within the study was caused by natural hydrodynamic events associated with the seabed and scouring. The changes in the faunal continuum reflected the gradual changes in sediment type and depth (Halcrow, 2003).

There are a number of organic compounds on the priority substances list, of which the most relevant is the PAH family. There are moreover four heavy metals cadmium (Cd); nickel (Ni); lead (Pb); mercury (Hg). PAH, Cd and Hg are furthermore high priority compounds that should be phased out within the next 20 years. We will focus on these substances in this screening assessment.

Bivalve molluscs are good indicators of heavy metal contamination in coastal areas. User et al. (1997) compared the levels of heavy metals in two different bivalves along the Atlantic coast of southern Spain. They found that out of the seven sites sampled the samples from the Bay of Gibraltar were the median value of the sites with regards to the overall mean metal pollution index (MPI) for both species of bivalves. However, the Bay of Gibraltar had the highest mean Ni concentration compared to the other sites, which the authors attributed to Acerinox, a stainless steel factory located in Los Barios. The heavy metal concentrations found in the bivalves did not exceed the maximum permissible levels for human consumption. Cesar et al. (2007) also compared the Bay of Gibraltar and the Guadarranque River's estuary to *Riá* of Huelva and Cádiz Bay, this time with a focus on the levels of heavy metal in the sediment. They found that Ni; zinc (Zn) and PAH in the Guadarranque River's estuary exceeded the Sediment Quality Guidelines. These were however, not exceeded at the sampling station in the Bay of Gibraltar. The results showed that samples taken with regards to heavy metals in the Bay of Gibraltar were on par or below the levels found in the *Riá* of Huelva and Cádiz Bay. The PAH levels were however, higher (0.712 mg/kg) in the sediment of the Bay of Gibraltar, at the mouth of the Guadarranque River. The findings of elevated PAH levels were confirmed in another study by the same group of researchers (Morales-Caselles et al. 2007), that suggest a chronic exposure to PAH due to continuous minor oil spills in the Bay of Gibraltar from the industrial activities in the bay. Dach et al. (1997) moreover, showed how long range transported PAH sorbed to suspended particulate matter in the western Mediterranean seawater due to hydrological and mixing forces tend to reach their maximum concentration in the Straits of Gibraltar.

#### Conclusions

PAH and Ni levels are elevated in the Guadarranque River's estuary and the Bay of Gibraltar. Industrial activity has been cited a potential cause of the elevated concentrations found in the sediment. The levels of these contaminants in bivalves do not exceed the limits according to User et al. (1997). Hydrological conditions may cause detection of elevated concentrations of suspended particles and compounds, hereunder PAH, in the Straits of Gibraltar. The human exposure to Ni and PAH from the Bay

Area is uncertain, one exposure route could be dermal exposure via beach sand. However levels in Gibraltar beach sand were below instrumental detection limits (Mesilio, 2004) suggesting that these parameters are not of significant concern in Gibraltar relative to other Spanish sites.

### 4.1.2 Soil

The soil compartment in Gibraltar comprises: soil/dirt; rock/geology; and the beaches. These are the potential exposure routes. The exposure via the beaches is described above.

#### Soil

**Background**

Soil contamination is reported for site specific contamination, reclamation, and restoration purposes. There is however, no routine monitoring and reporting of soil contamination levels in Gibraltar to provide a background value (Gibraltar: Environment Matters, 2006; 2007; 2008). Due to the topography in Gibraltar as well as the dense and highly urbanized population, exposure of contaminants via soil to the general public e.g. via home-grown produce and husbandry, children's play, etc. where direct contact with soil may occur is likely to be very limited compared to most other places. The relatively hot and arid conditions in Gibraltar would moreover suggest that human exposure from soil contaminants would more likely be via dust particles, which would be reflected in the atmospheric measurements.

**Conclusions**

The direct exposure route from soil to humans in Gibraltar is limited. As a result, this compartment of the environment is not likely to pose a specific elevated cancer risk to the population in Gibraltar. There is no publicly available routine monitoring data of potential carcinogenic contaminants of concern in the soil compartment in Gibraltar.

#### Radon

**Background**

Radon is a significant contributor to pulmonary cancer in the World. According to the World Health Organization (WHO) radon is globally one of the primary causes of lung cancer. In 2009 the WHO stated that up to 14 % of all lung cancers in the USA are caused by exposure to radon. Radon has been identified as the second leading cause of lung cancer in the United States (second only to smoking.), the U.S. Environmental Protection Agency reports that radon causes between 15,000 and 22,000 lung cancer deaths every year in the United States. As we breathe, radon products are deposited on the cells lining the airways where the alpha particles emitted can damage DNA and potentially cause lung cancer. In 2009 the recommended action level of radon exposure in homes was lowered from 4.0 to 2.7 pCi/l (or 148 to 100 $Bq/m^3$) by the WHO. The risk of lung cancer increases by 16 % per 100 $Bq/m^3$ increase in radon concentration. The primary route exposure is indoor air either from the ground or building materials in houses.

Radon is a naturally occurring, odourless, and colourless gas produced by the breakdown of uranium in soil, rock, and water, the half life of radon is 3.82 days. As radon is a gas, it can enter buildings through openings or cracks in the foundation. The radon gas itself decays into radioactive solids, called radon daughters. The radon daughters attach to dust particles in the air, and can be inhaled. The inhalation of radon daughters has also been linked to lung cancer, leukaemia, cancer to the kidney and melanoma (WHO, 2010c)

Figure 3.1 below shows how radon can enter a house.

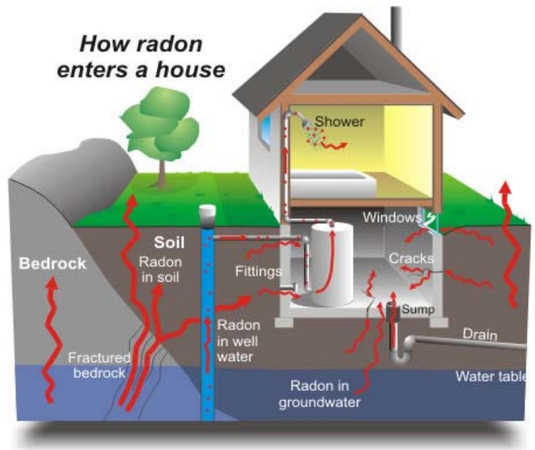



Figure 3.1 Domestic radon pathways.

We do not have measured radon levels from Gibraltar, hence we have examined the theoretical radon risk based on the literature. The geology in Gibraltar is unique and as such is an important specific environmental condition. The Rock is comprised primarily of Jurassic age carboniferous limestone and dolomite. Uranium is often redistributed by water and re-deposited into limestones and dolomites. The global average Uranium content in limestone is 2.0 parts per million (ppm) - with substantial variations (Gilmore et al. 2000), indicating that radon levels as a product of decaying Uranium in Gibraltar should be considered. Radon gas once released into the open air is normally dispersed, hence the ambient outdoor radon levels are usually very low. The global average outdoor radon level varies between 5 and 15 $Bq/m^3$ (WHO, 2010c).

The maximum radioactivity measured in ambient air at Coaling Island in Gibraltar in 2000 was 3.4 $Bq/m^3$ (Radiation monitoring results, Gibraltar Environmental Agency, 14/8 2000 – 6/2-2001). In poorly ventilated enclosed spaces, including natural caves and basements of houses, harmful concentrations may build up (Gilmore et al. 2002). Since, the majority of Gibraltarians do not live in or own a basement the direct indoor air exposure from the geology is expected to be low.

Radon is moreover the most water soluble of the noble gases and may be transported via water (Gilmore et al. 2000), therefore The *WHO guidelines for drinking water quality* recommend repeated measurements to be implemented if radon in public drinking water supplies exceeds 100 Bq/l (see drinking water safety 3.1.1.1 where levels of 0.005 and 0.02 Bq/l have been detected in Gibraltar drinking water). To date, epidemiological studies have not found an association between radon in drinking water and cancer of the digestive and other systems (WHO, 2010c).

**Conclusions**

No measurements of radon in Gibraltar air samples were available in this study, hence the assessment here is based on measurements elsewhere. The conclusion is that radon can be a significant pulmonary carcinogen generally, and given the limestone geology in Gibraltar radon levels could be considered for future monitoring.

### 4.1.3 Miscellaneous parameters

There are a few miscellaneous environmental parameters that are beyond the more traditional environmental compartments. Here we focus on two parameters where we have emerging concerns and evidence of relationship to cancer.

**Noise**

**Background**

Urban outdoor environmental noise is a recognized stressor on human health. The primary effects are stress and mental health related and subsequent increased cardiovascular risks. Indirectly these impacts may reduce the resiliency towards cancer (Moudon, 2009; Ising and Kruppa, 2004). In 2002 the Council Directive 2002/49/EC Environmental Noise Directive (END) came in to force in the EU. The END defined different sources of noise that member states should monitor and report to the public. The only source relevant to Gibraltar is major roads with more than 6 million vehicles passages per year (Government of Gibraltar, 2009). The World Health Organization Europe reviewed the state-of-the-science related to environmental noise. The WHO placed emphasis on night noise as this is the most critical period related to noise and health effects due to noise induced sleep disturbances that increases stress and mortality in the population. Hence the focus in this assessment is also on the night noise exposure ($L_{night}$).

**Results**

The European Environment Agency (EEA) reports the population exposures to noise in the EU according to reporting of the member states following the END (EEA, 2010). Table 3.2 below compares the percentage of the population exposed different bands of measured $L_{night}$ in dB from road noise between EU 27; 104 EU cities; Spain; urban Spain; and Gibraltar.

Table 3.2 Percentage of population exposed to $L_{night}$ from roads.

| dB | EU-27* | Mean 104 EU cities* | Spain* | Mean seven Spanish cities* | Malaga* | Gibraltar[#] |
|---|---|---|---|---|---|---|
| 50-54 | 22 | 25±20sd[1)] | 22 | 20±13sd | 9 | 1.3 |
| 55-59 | 10 | 10±6.7sd | 19 | 17±10sd | 10 | 5.5 |
| 60-64 | 5 | 5±4.5sd | 11 | 11±7sd | 20 | 4.4 |
| 65-69 | 1 | 1±2sd | 4 | 4±3sd | 7 | 1.7 |
| >70 | 0 | 0±0.50sd | 0 | 0±0sd | 0 | 0 |

Sources: *EEA, 2010; [#] Government of Gibraltar, 2009; [1)] standard deviation.

The percentage of the total population exposed to environmental noise from roads in Gibraltar is lower than those found in Spain, Spanish cities and the closest Spanish city Malaga. The exposure in the lower 50-59 dB bands is lower than the averages found in the EU, and the upper bands from 60 to >70 dB is on par to the averages found in the EU countries and cities in the EU.

#### Conclusions

According to the END directive the only relevant environmental noise source in Gibraltar is road noise. The environmental noise in Gibraltar from roads is not significantly different from noise found in most other urban places in the EU, in fact it is lower than what is found in Spain, and does thus not constitute a specific and elevated cancer risk to the population of Gibraltar.

### Electromagnetic fields (EMF) and Extremely Low Frequency fields (ELF)

#### Background

There have been concerns and debates about the role of EMF in relation to cancer. EMF are areas of energy that surround any electrical device. EMF are produced by power lines, electrical wiring, and appliances. Electric fields are easily shielded or weakened by walls and other objects, whereas magnetic fields are not. Since magnetic fields are more likely to penetrate the body, they are the component of EMF that are usually studied in relation to cancer. Overall, there is limited evidence that magnetic fields cause childhood leukaemia and there is inadequate evidence that these magnetic fields cause other cancers in children. Studies of magnetic field exposure from power lines and electric blankets in adults show little evidence of an association with leukaemia, brain tumours or breast cancer. Past studies of occupational magnetic field exposure in adults showed very small increases in leukaemia and brain tumours. However, more recent, well-conducted studies have shown inconsistent associations with leukaemia, brain tumours, and breast cancer (U.S. NIH, 2010).

The World Health Organization (WHO) convened a Task Group of scientific experts in October 2005 to assess any risks to health that might exist from exposure to ELF electric and magnetic fields in the frequency range >0 to 100,000 Hz (100 kHz). While IARC examined the evidence regarding cancer in 2002, this Task Group reviewed evidence for a number of health effects, and updated the evidence regarding cancer. The conclusions and recommendations of the Task Group are presented in a WHO Environmental Health Criteria (EHC) monograph. Following a standard health risk assessment process, the Task Group concluded that there are no substantive health issues related to ELF electric fields at levels generally encountered by members of the public.

Much of the scientific research examining long-term risks from ELF magnetic field exposure has focused on childhood leukaemia. In 2002, IARC published a monograph classifying ELF magnetic fields as "possibly carcinogenic to humans". This classification is used to denote an agent for which there is limited evidence of carcinogenicity in humans and less than sufficient evidence for carcinogenicity in experimental animals (other examples include coffee and welding fumes). This classification was based on pooled analyses of epidemiological studies demonstrating a consistent pattern of a two-fold increase in childhood leukaemia associated with average exposure to residential power-frequency magnetic field above 0.3 to 0.4 μT (microtesla). The Task Group concluded that additional studies since then do not alter the status of this classification.

However, the epidemiological evidence is weakened by methodological problems, such as potential selection bias. In addition, there are no accepted biophysical mechanisms that would suggest that low-level exposures are involved in cancer development. Thus, if there were any effects from exposures to these low-level fields, it would have to be through a biological mechanism that is as yet unknown. Additionally, animal studies have been largely negative. Thus, on balance, the evidence related to childhood leukaemia is not strong enough to be considered causal (WHO, 2010d).

In 2002 the Government of Gibraltar commissioned an assessment of the electromagnetic emissions in Gibraltar. The results of the survey based on measurements at North mole and the Haven. The measurements showed that the exposures were between 719 and 1645 times lower than the maximum exposure levels for the general public, and that the exposures are unlikely to cause harm (Stanley and Solanki, 2002).

#### Conclusion

There are no significant power lines or other large scale electrical installations in Gibraltar that warrant a specific concern regarding EMF and ELF. Moreover, the causal link between EMF and ELF and cancer, especially childhood leukaemia, is limited. On this basis Gibraltar does not appear to be a high cancer risk area due to EMF and ELF.

### 4.1.4 Air

The potential sources and levels of airborne exposure of carcinogens and their potential risk to the population of Gibraltar is investigated through:

- Air monitoring data in Gibraltar.
- Reported air emission rates from industries in the Bay Area and adjacent Spanish municipalities.
- Modelled air concentrations in Gibraltar.
- Threshold and risk values for exposure of carcinogens and co-carcinogens to humans.
- Measured concentrations in other EU cities.

#### Air Quality Monitoring in Gibraltar

The Gibraltar Air Quality Monitoring Network started in February 2005 with some non-automatic data going back to 2000. The network consists of three automatic monitoring stations and a non-automatic network comprising four filter units and 27 diffusion tube sampling locations.

The automatic network produces hourly pollutant concentrations, with data being collected electronically from individual sites. The non-automatic networks measure less frequently; daily, weekly or monthly, and samples are collected by diffusion tubes or filters. These samples are then subjected to chemical analysis, and final pollutant concentrations are calculated from these results. Air quality data are continuously being updated and is available to the public on Gibraltar Air Quality website (2010).

Table 3.3 Pollutants monitored in Gibraltar Air Quality Monitoring Network. Only pollutants of potential relevance as carcinogens and co-carcinogens are listed.

| | Automatic air pollution measurements | | | Non-automatic air pollution measurements | |
|---|---|---|---|---|---|
| Pollutant | Rosia Road | Bleak House | Witham's Road | Three filter units[2)] | Diffusion tube sampling (27 sites)[2)] |
| $PM_{10}$ | x | x | | x | |
| $PM_{2.5}$ | x | | | x | |
| $SO_2$ | x | | | | |
| $NO_x$ | x | x | x | | |
| $NO_2$ | x | x | x | | x |
| Arsenic | | | | x | |
| Cadmium | | | | x | |
| Lead | | | | x | |
| Nickel | | | | x | |
| PAH[1)] | | | | x | |
| Benzene | x | | | | x |
| Ethyl benzene | x | | | | x |
| 1,3-butadiene | x | | | | |
| Ozone | | x | | | |

[1)] 16 species are covered. Benzo(a)pyrene concentration is used as marker for the carcinogenic risk of PAHs.

[2)] Sites affected by specific pollution and Rosia Road and Bleak House for bias checking.

Monitoring sites were selected to include areas likely to be affected by emission sources, such as heavy traffic, petrol stations, power generation and vents from fuel storage, as well as being representative of general background levels.

Diffusion tube sampling provides average ambient concentrations of pollutants; however they do not provide the same accuracy as an automatic sampler. Diffusion tubes are bias checked at the automatic stations and are a supplement for information on spatial distribution of pollutants across Gibraltar (Targa, 2008; Soiza, 2008).

Conclusions from the most recent reporting of air quality (Annual Report 2008) state that there was no exceedence of the hourly and daily mean sulphur dioxide and annual mean benzene objectives contained in the national legislation or within the European Air Quality Directives or Daughter Directives (WHO, 2000).

Nitrogen dioxide exceeded the annual mean objective of 40 $\mu g/m^3$, which should be met by 2010 (Figure 4.1 page 84). Measurements and modelling indicate that elevated nitrogen dioxide levels are a result of emissions from the OESCO power station and the Inter Services Generating Station.

The annual mean for nickel in 2008 slightly exceeded the target value of 20 $\mu g/m^3$ (at 20.4 $\mu g/m^3$) (Figure 5.1c page 86) and it is suspected that the elevated levels are attributable to heavy industry in neighbouring Spain and shipping sources (Abbott, 2009b). The annual mean in 2009 was 12.05 $\mu g/m^3$.

In 2008 there was a decrease in exceedances of the daily mean particulate matter ($PM_{10}$) European limit value of 50 $\mu g/m^3$, compared to previous years. However, the maximum number of exceedances is not met (Figure 4.2, page 83). A study to identify and quantify sources of particulate matter (Kent et al., 2010 and Abbott, 2009c) yielded that the most significant sources affecting $PM_{10}$ concentrations at Rosia Road air quality monitoring station were the local area of unmade land and associated bulk handling operations. Other significant contributions were transboundary sources, resuspended road dust, exhaust emissions, African dust and also sea salt; however no quantification of the latter has yet been possible.

For ozone the maximum daily eight hour mean of 120 $\mu g/m^3$ was exceeded on seven days during 2008, with a air quality limit of no more than 25 exceedances per calendar year averaged over three years. The maximum hourly mean was recorded at 140 $\mu g/m^3$, which is below the EU Information Threshold of 180 $\mu g/m^3$ and the EU Alert Threshold of 240 $\mu g/m^3$.

The annual average concentrations of cadmium, arsenic and PAHs were below their corresponding target values in the European Air Quality Directives or Daughter Directives (WHO, 2000).

The Gibraltar air monitoring data for 2008 and 2005 are used to compare with modelled concentrations (Table 3.11 page 47) and furthermore to compare with cancer risk values and concentration levels in EU cities (Table 4.1 page 84).

#### Sources and pollutants

Sources that cause environmental airborne exposure can be defined by their spatial extent of emission as a point source, line source or an area source:

<u>Point sources:</u>

- Industrial sources in Bay Area.
- Diesel generators in Gibraltar.
- Ships bunkering in the Bay.
- Ships at anchor in the Ports of Gibraltar and Algeciras.

<u>Line sources:</u>

- Road traffic within Gibraltar.
- Ships travelling through the Straits of Gibraltar.
- Ships travelling to and from the Ports of Gibraltar and Algeciras.

<u>Area sources:</u>

- Diffuse emission from adjacent municipalities.

A comprehensive literature review of all available official emission data from industries and activities was made with respect to priority pollutants in the area. We have drawn on emission data that industries are committed to report to e.g. the United Nations Economic Commission for Europe (UNECE) Convention on Long Range Transboundary Air Pollution (CLRTAP, 2010), and data from the Pollutant Release and Transfer Registers (E-PRTR, 2010). Furthermore the gross list of pollutants is compiled from emission inventory guidelines for road traffic and ships

(EMEP/CORINAIR, 2007), site specific measurements from e.g. diesel stacks (Moore, 2004), literature on flaring (Strosher, 1996; Seebold, 2009; CONCAWE, 2009; EMEP/CORINAIR 2007) and from municipal reporting of various point and diffuse sources (Junta de Andalucia, 2010). The sources and their associated pollutants that are relevant to cancer and exposure via the environment are listed in Table 3.4.

Table 3.4 Sources and pollutants that are relevant in relation air and to cancer (carcinogens and co-carcinogens).

| | Gibraltar local | | | Adjacent Spanish municipalities | | |
|---|---|---|---|---|---|---|
| | Road traffic (diesel and gasoline road transport) | Ships (bunkering, anchoring, travelling in bay, and strait) | Diesel generators | Industries | Flaring CEPSA | Various point and diffuse sources |
| Pollutant | Line source | Point and line sources | Point source | Point source | Point source | Area source |
| Chlorine and its inorganic compounds | | | | C | | D |
| Particles (not specified) | | | E | | B | D |
| $PM_{2.5}$ | | A | | | | D |
| $PM_{10}$ | A | A | A | C | | D |
| Arsenic | | A | | C | B | D |
| Cadmium | A | A | A | C | | D |
| Chromium | A | A | A | C | B | D |
| Lead | A | A | A | C | | D |
| Mercury | | A | | C | B | D |
| Nickel | A | A | A | C | B | D |
| NMVOC (not specified) | | | E | C | | D |
| 1,3-butadiene | A | | A | | | |
| Acetaldehyde | A | | A | | B | |
| Acrolein | A | | A | | B | |
| Benzene | A | A | A | C | B | D |
| Crotonaldehyde | A | | A | | | |
| Ethylbenzene | A | A | A | | B | |
| Formaldehyde | A | | A | | B | |
| Furans (unspecified) | A | | A | | | |
| Hexachlorobenzene | | | | C | | D |
| Hexachlorocyclohexane (Lindane) | | | | C | | D |
| Isoprene | A | | A | | | |
| PCDD/F (dioxins not specified) | A | A | A | C | B | D |
| Styrene | A | | A | | B | |
| Tetrachloroethylene | | | | C | | D |
| Trichloroethylene | | | | C | | D |
| Trichloromethane | | | | C | | |
| $SO_x$ (/$SO_2$ for PRTR data) | A | A | A | C | B | D |
| $NO_x$ (/$NO_2$ for PRTR data) | A | A | E | C | B | D |
| PAHs (not specified)[1)] | A | A | A | C | B | D |
| Benzo(b)fluorene | A | A | A | | | |
| Benzo(a)anthracene | A | A | A | | B | |
| Benzo(a)pyrene | A | A | A | C | B | |
| Benzo(b)fluoranthene | A | A | A | C | | |
| Benzo(j)fluoranthene | A | A | A | | | |
| Chrysene | A | A | A | | B | |
| Dibenzo(a,h)anthracene | A | A | A | | | |
| Dibenzo(a,j)anthracene | A | A | A | | | |
| Dibenzo(a,l)pyrene | A | A | A | | | |
| Indeno(1,2,3-cd)pyrene | A | A | A | C | B | |
| Naphthalene | A | | A | | B | |

[1)] Six PAHs are covered by PRTR: benzo(a)pyrene, benzo(ghi)perylene, benzo(k)fluoranthene, fluoranthene, indeno(1,2,3-cd)pyrene and benzo(b)fluoranthene.

A: Potential pollutants from EMEP/CORINAIR (2007). It is not possible to calculate emissions of some pollutants due to data gaps in emission factors and information of e.g. vehicle traffic speciation. Pollutants from diesel generators correspond to diesel traffic.

B: Flaring; no measurements for the CEPSA refinery have been found. Information on pollutants are from other installations, e.g. Alberta study (Strosher, 1996) and Canadian Public Health Association (2000). Fugitive emissions and leaks are also relevant and are comprised in pollutants from flaring.

C: E-PRTR (2010) holds reported emission data for facilities that exceed specific pollutant threshold values. The thresholds have been fixed at a level that aims to cover about 90 % of the emissions. This implies that only large and medium sized industrial plants, which are covered in the Annex I of the PRTR regulation (E-PRTR Annex I, 2010) and not low emissions from smaller installations, are reported. Some potentially relevant pollutants may not be covered by the E-PRTR pollutant list.

D: 2005 emission rates (t/year) from nearby municipalities (no more than approx. 10 km from Gibraltar). These comprise various (diffuse) sources: extraction and treatment of minerals, agriculture, road paving, biogenic, fuel distribution, use of refrigerants and propellants, animal husbandry, petrol stations, roof waterproofing, forest fires, petrochemical industry, food industry, non-metallic materials industry, metal industry, chemical industry, dry cleaning, agricultural machinery, other transportation and mobile equipment, production of electricity, commercial and institutional sector, households, railways, road traffic, maritime traffic, solid waste treatment, solvent use. Municipal emissions are entered as area sources in the exposure model. E-PRTR facilities are not specifically discernible in the municipal emission Figures; their emission rates are however subtracted from municipal emission rates to avoid double counting.

E: Diesel generators. Only particles, unspecified Non Methane Volatile Organic Compounds (NMVOCs) and Oxides of Nitrogen $NO_x$ have been measured on site. The three diesel generators situated in Gibraltar emit untreated exhaust into the ambient air. Potential pollutants are as stated for diesel engines.

Previous studies have investigated the contribution to primarily $PM_{10}$, $NO_x$, $NO_2$ and $SO_2$ from ships, road traffic and diesel generators (Abbott 2007, 2009a, 2009b, 2009c; Kent et al. 2010). This study only includes emission data that have been verified according to national and international reporting guidelines and thus permit a realistic and accurate assessment of exposure to the people in Gibraltar. Consequently this study investigates the contribution to the air quality in Gibraltar from industries in the Bay Area and from diffuse emissions from adjacent Spanish municipalities.

The following industries, with main activities, are included:

- CEPSA: Refinery.
- Acerinox: Manufacture of basic iron and steel and of ferro-alloys.
- Cogeneracion de Interquisa: Production of electricity.
- Interquisa (Fabrica Puente de Guadarranque): Manufacture of other organic basic chemicals.
- Endesa (Central Termica Ciclo Combinado San Roque Grupo 2): Production of electricity.
- GAS Natural SDG: Production of electricity.
- Central Termica Los Barrios: Production of electricity.
- CT Bahia De Algeciras: Production of electricity.
- Nueva Generadora Del Sur: Production of electricity.
- Lubricantes Del Sur: Manufacture of refined petroleum products.
- Petresa (Fabrica Puente De Mayorga): Manufacture of other organic basic chemicals.
- Generacion Electrica Peninsular: Production of electricity.
- UTE Dramar Andalucia: Treatment and disposal of hazardous waste.
- Edar De La Linea De La Concepcion: Sewerage.
- Torraspapel (Fabrica De Algeciras): Manufacture of paper and paperboard.

- Ceramica La Esperanza: Manufacture of bricks, tiles and clay products for construction.

And the following municipalities, with surface areas in brackets, are included:

- Algeciras (86 $km^2$).
- Los Barrios (331.33 $km^2$).
- La Linea De La Concepcion (19.27 $km^2$).
- San Roque (146.88 $km^2$).
- Castellar De La Frontera (178.84 $km^2$).

Figure 3.3 (page 40) shows a map with industries and adjacent municipalities.

The tidal scale of emissions can vary considerably between sources. Road traffic and industrial activities have a uniform annual emission pattern, but show a distinctly varying daily emission pattern, e.g. traffic on Rosia Road has two peaks; morning and afternoon. Diesel generators show a seasonal and daily pattern and ship activities may show more variable emissions regardless of time of day and season. The tidal emission pattern influence the variations in the air quality, and consequently different air quality limit values apply for the public health rules. Running 8-hour mean, 15-minute mean, hourly mean, daily mean and annual mean values may be applied as limit or target values for a pollutant.

The emission rates compiled in Tables 3.5, 3.6 and 3.7 in the next section are total annual emissions, which are founded on mean annual activity data or estimated or measured annual emission rates. Therefore the models cannot take daily variations into account.

#### Emission rates

The PRTR regulation Annex I and municipal reporting do not cover all relevant pollutants listed in Table 3.4. Most notably the different PAHs have been aggregated into a sum of PAHs. From a risk perspective benzo(a)pyrene will be used as a worst-case proxy. Emission rates for metals, $SO_x$, $NO_x$ are available. Benzene is reported, however, a number of NMVOCs are not covered, namely 1,3-butadiene and ethyl benzene, which are included and reported in the Gibraltar Air Quality Programme. PM2.5 and PM10 emission rates are reported and municipal data for unspecified particles are furthermore available.

Quantification of other relevant pollutants and emission rates from other sources requires data on road traffic counts and vehicle types, ship traffic and types, flaring activities and emission factors for all pollutants related to these activities and diesel generators. Verified data are not available and to avoid inaccurate emission rates these sources and pollutants are not considered in this study.

Two different scenarios are defined from the available data:

- 2005 emissions comprise the most complete set of emission data with industries and adjacent municipalities.
- 2008 emissions represent the most recent data set for industries, but lack municipal data.

From these scenarios source apportionment to the Gibraltar air quality and the emission trend for individual pollutants, industries and municipalities, between 2005 and 2008, is assessed. The year 2005 also represents a worst-case year with highest emission rates for many pollutants, Figure 3.2 (page 34-37) shows trends in emission rates for critical pollutants.

In Table 3.5 2005 emission rates for industries as reported to PRTR are shown, in Table 3.6 2005 emission rates for adjacent Spanish municipalities are shown. To avoid double counting industry 2005 emission rates are subtracted from their respective municipality 2005 emission rates. Only 2005 data are available for municipalities. In Table 3.7 2008 emission rates for industries are shown.

Table 3.5 2005 emission rates (tonnes/year) for industries in Bay Area (E-PRTR, 2010).

| Pollutant | CEPSA | Acerinox | Cogeneracion de interquisa | Interquisa | Endesa | GAS natural SDG | Central termica Los Barrios | CT Bahia De Algeciras |
|---|---|---|---|---|---|---|---|---|
| Chlorine and its inorganic compounds | 19.5 | - | - | - | - | - | 71 | - |
| $PM_{2.5}$ | | | | | | | | |
| $PM_{10}$ | 544 | 50.8 | - | - | - | - | 1020 | 76 |
| Particles (unspecified) | | | | | | | | |
| Arsenic | 0.023 | - | - | - | - | - | - | 0.0254 |
| Cadmium | 0.0297 | - | - | - | - | - | - | - |
| Chromium | 1.98 | 0.511 | - | - | - | - | 0.242 | - |
| Lead | - | - | - | - | - | - | 0.371 | - |
| Mercury | 0.0238 | - | - | - | - | - | - | - |
| Nickel | 7.41 | 0.102 | - | - | - | - | 0.307 | 1.62 |
| NMVOC (unspecified) | 1300 | - | - | 1430 | - | - | - | - |
| Benzene | 33.5 | - | - | 54.6 | - | - | - | - |
| Hexachlorobenzene | - | - | - | - | - | - | - | - |
| Hexachlorocyclohexane (Lindane) | - | - | - | - | - | - | - | - |
| PCDD/F (dioxins unspecified) | - | - | - | - | - | - | - | - |
| Tetrachloroethylene | - | - | - | - | - | - | - | - |
| Trichloroethylene | - | - | - | - | - | - | - | - |
| Trichloromethane | - | - | - | - | - | - | - | - |
| $SO_x$ (/$SO_2$ for PRTR data) | 13400 | - | - | - | - | - | 17300 | 2870 |
| $NO_x$ (/$NO_2$ for PRTR data) | 1910 | 112 | 288 | 128 | 507 | 254 | 8020 | 1010 |
| PAH[1)] | 0.965 | - | - | 8.21 | - | - | - | - |

[1)] PRTR: six species, monitoring: B(a)P

blank: not reported

-: below reporting threshold

Table 3.5 (*continued*) 2005 emission rates (tonnes/year) for industries in Bay Area (E-PRTR, 2010).

| Pollutant | Nueva generadora del sur | Lubricantes del sur | Petresa | Generacion electrica peninsular | UTE dramar andalucia | Edar de la linea de la concepcion | Torraspapel | Ceramica la esperanza |
|---|---|---|---|---|---|---|---|---|
| Chlorine and its inorganic compounds | - | - | - | - | - | - | - | - |
| $PM_{2.5}$ | | | | | | | | |
| $PM_{10}$ | 81.6 | - | - | - | - | - | - | - |
| Particles (unspecified) | | | | | | | | |
| Arsenic | - | - | - | - | - | - | - | - |
| Cadmium | - | - | - | - | - | - | - | - |
| Chromium | - | - | - | - | - | - | - | - |
| Lead | - | - | - | - | - | - | - | - |
| Mercury | - | - | - | - | - | - | - | - |
| Nickel | - | 1.22 | 0.211 | - | - | - | - | - |
| NMVOC (unspecified) | - | 331 | - | - | - | - | - | - |
| Benzene | - | - | 2.43 | - | - | - | - | - |
| Hexachlorobenzene | - | - | - | - | - | - | - | - |
| Hexachlorocyclohexane (Lindane) | - | - | - | - | - | - | - | - |
| PCDD/F (dioxins unspecified) | - | - | - | - | - | - | - | - |
| Tetrachloroethylene | - | - | - | - | - | - | - | - |
| Trichloroethylene | - | - | - | - | - | - | - | - |
| Trichloromethane | - | - | - | - | - | - | - | - |
| $SO_x$ (/$SO_2$ for PRTR data) | - | 1110 | 1300 | - | - | - | - | - |
| $NO_x$ (/$NO_2$ for PRTR data) | 386 | 225 | 428 | 1720 | - | - | - | - |
| PAH[1)] | - | - | - | - | - | - | - | - |

[1)] PRTR: six species, monitoring: B(a)P

blank: not reported

-: below reporting threshold

Table 3.6 2005 emission rates (tonnes/year) for various sources in adjacent municipalities.

| Pollutant | Algeciras | Los Barrios | La Linea De La Concepcion | San Roque | Castellar De La Frontera |
|---|---|---|---|---|---|
| Chlorine and its inorganic compounds | 0.04 | 0.03 | 0.01 | 13.0 | 0 |
| $PM_{2.5}$ | 508 | 385 | 45.0 | 442 | 13.2 |
| $PM_{10}$ | 519 | 59.9 | 51.9 | 70.7 | 14.2 |
| Particles (unspecified) | 535 | 5660 | 62.1 | 1380 | 17.7 |
| Arsenic | 0.024 | 0.00119 | 0.00009 | 0.0272 | 0.00001 |
| Cadmium | 0.00314 | 0.00522 | 0.00047 | 0.0345 | 0.00003 |
| Chromium | 0.0181 | 0.00168 | 0.00366 | 0 | 0.00024 |
| Lead | 0.0479 | 0.0680 | 0.00714 | 0.232 | 0.00237 |
| Mercury | 0.00258 | 0.262 | 0.00023 | 0.00879 | 0 |
| Nickel | 1.39 | 0.00145 | 0.0949 | 0 | 0.00027 |
| NMVOC (unspecified) | 4310 | 2320 | 740 | 2460 | 809 |
| Benzene | 41.8 | 0.97 | 0 | 8.63 | 0 |
| Hexachlorobenzene | 0.00003 | 0.0168 | 0.00632 | 0.0025 | 0.00193 |
| Hexachlorocyclohexane (Lindane) | 0.00003 | 0.00067 | 0.0101 | 0.00399 | 0.00307 |
| PCDD/F (dioxins unspecified) | 0.00000031 | 0.00000008 | 0.00000003 | 0.00000007 | 0.00000001 |
| Tetrachloroethylene | 5640 | 1040 | 3150 | 1330 | 147 |
| Trichloroethylene | 6750 | 1250 | 3770 | 1590 | 176 |
| Trichloromethane | 0 | 0 | 0 | 0.22 | 0 |
| $SO_x$ (/$SO_2$ for PRTR data) | 3240 | 39.4 | 26.9 | 511 | 1.86 |
| $NO_x$ (/$NO_2$ for PRTR data) | 5070 | 398 | 243 | 0 | 79.3 |
| PAH (unspecified) | 0.0566 | 0.0289 | 0.0385 | 0.106 | 0.00666 |

Table 3.7 2008 emission rates (tonnes/year) for industries in Bay Area (E-PRTR, 2010).

| | CEPSA | Acerinox | Cogeneracion de interquisa | Interquisa | Endesa | GAS natural SDG | Central termica Los Barrios | CT Bahia De Algeciras |
|---|---|---|---|---|---|---|---|---|
| Chlorine and its inorganic compounds | 19.4 | - | - | - | - | - | 53.2 | - |
| $PM_{2.5}$ | | | | | | | | |
| $PM_{10}$ | 427 | - | - | - | - | - | 399 | - |
| Particles (unspecified) | | | | | | | | |
| Arsenic | 0.0229 | - | - | - | - | - | - | |
| Cadmium | 0.0229 | - | - | - | 0.013 | - | - | - |
| Chromium | 1.97 | 0.251 | - | - | - | - | - | - |
| Lead | - | - | - | - | - | - | - | - |
| Mercury | - | - | - | - | - | - | 0.0182 | - |
| Nickel | 7.3 | - | - | - | - | - | - | |
| NMVOC (unspecified) | 408 | - | - | 937 | - | - | - | - |
| Benzene | 13 | - | - | 41.4 | - | - | - | - |
| Hexachlorobenzene | - | - | - | - | - | - | - | - |
| Hexachlorocyclohexane (Lindane) | - | - | - | - | - | - | - | - |
| PCDD/F (dioxins unspecified) | - | - | - | - | - | - | - | - |
| Tetrachloroethylene | - | - | - | - | - | - | - | - |
| Trichloroethylene | - | - | - | - | - | - | - | - |
| Trichloromethane | - | - | - | - | - | - | - | - |
| $SO_x$ (/$SO_2$ for PRTR data) | 8180 | - | - | - | - | - | 7010 | - |
| $NO_x$ (/$NO_2$ for PRTR data) | 1640 | 147 | 786 | - | 331 | 315 | 3640 | - |
| PAH[1)] | 0.668 | - | - | - | - | - | - | - |

[1)] PRTR: six species, monitoring: B(a)P

blank: not reported

-: below reporting threshold

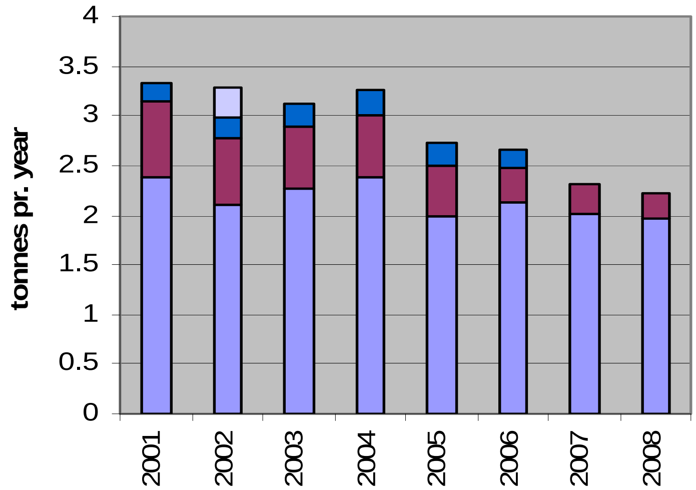
Table 3.7 (*continued*) 2008 emission rates (tonnes/year) for industries in Bay Area (E-PRTR, 2010).

| Pollutant | Nueva generadora del sur | Lubricantes del sur | Petresa | Generacion electrica peninsular | UTE dramar andalucia | Edar de la linea de la concepcion | Torraspapel | Ceramica la esperanza |
|---|---|---|---|---|---|---|---|---|
| Chlorine and its inorganic compounds | - | - | - | - | - | - | - | - |
| $PM_{2.5}$ | | | | | | | | |
| $PM_{10}$ | - | - | - | - | - | - | - | - |
| Particles (unspecified) | | | | | | | | |
| Arsenic | - | - | - | - | - | 0.00799 | - | - |
| Cadmium | - | - | - | - | - | - | - | - |
| Chromium | - | - | - | - | - | - | - | - |
| Lead | - | - | - | - | - | - | - | - |
| Mercury | - | - | - | - | - | - | - | - |
| Nickel | - | 1.03 | - | - | - | - | - | - |
| NMVOC (unspecified) | - | - | - | - | - | - | - | - |
| Benzene | - | - | - | - | - | - | - | - |
| Hexachlorobenzene | - | - | - | - | - | - | - | - |
| Hexachlorocyclohexane (Lindane) | - | - | - | - | - | - | - | - |
| PCDD/F (dioxins unspecified) | - | - | - | - | - | - | - | - |
| Tetrachloroethylene | - | - | - | - | - | - | - | - |
| Trichloroethylene | - | - | - | - | - | - | - | - |
| Trichloromethane | - | - | - | - | - | - | - | - |
| $SO_x$ (/$SO_2$ for PRTR data) | - | 700 | - | - | - | - | - | - |
| $NO_x$ (/$NO_2$ for PRTR data) | 210 | 158 | 325 | 1810 | - | - | - | - |
| PAH[1)] | - | - | - | - | - | - | - | - |

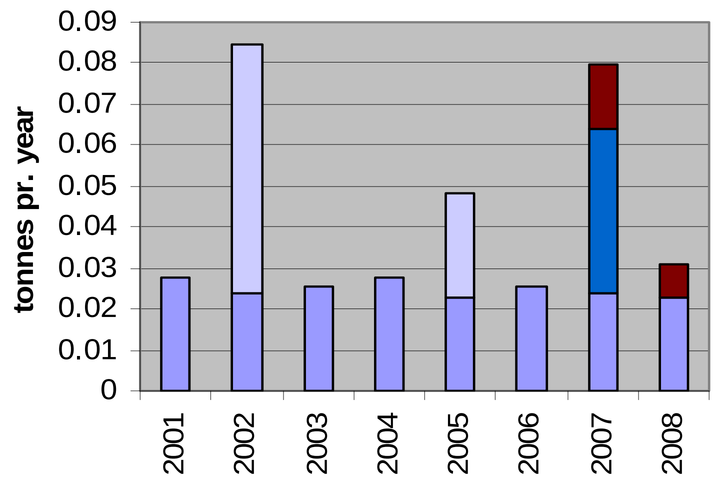
[1)] PRTR: six species, monitoring: B(a)P
blank: not reported
-: below reporting threshold

Trends in emission rates from 2001 to 2008 are shown in Figure 3.2 for carcinogenic and co-carcinogenic pollutants that are critical with respect to modelled air concentration risk and threshold values. There is a general decreasing trend in emission rates, however for chlorine, nickel and benzene there are constant emission rates in the latest years. Refinery CEPSA has relatively high emission rates for all pollutants and there is no apparent decreasing trend. Additionally Central Termica Los Barrios has relatively high emissions rates for chlorine, $PM_{10}$, $SO_x$ and $NO_x$. Acerinox has a relatively high emission rate for chromium. Petresa and Lubricantes del Sur have relatively high emission rates for nickel, and Interquisa has relatively high emission rates for benzene and PAHs with a notable decrease in PAH emissions from 2006 to 2007. For arsenic only CEPSA shows a continuous trend, whereas Central Termica Los Barrios, CT Bahia De Algeciras and Edar De La Linea De La Concepcion show dips and jumps, which may be attributed to emission rates that are around the reporting threshold value. Throughout the time-series there is only one reported lead emission rate, this is for Central Termica Los Barrios in 2005 (Table 3.5 page 29-30).

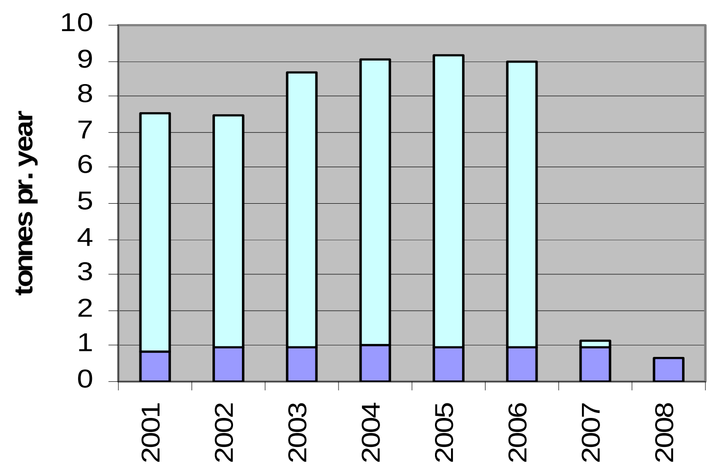
**Chromium**



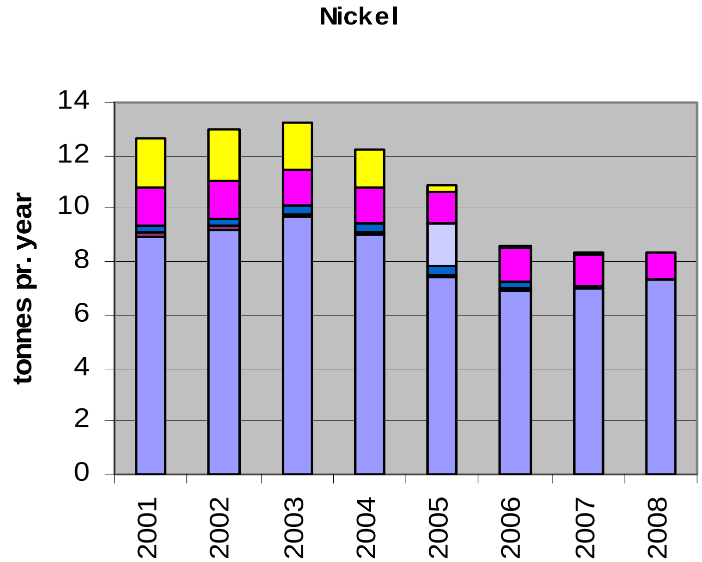

**Arsenic**

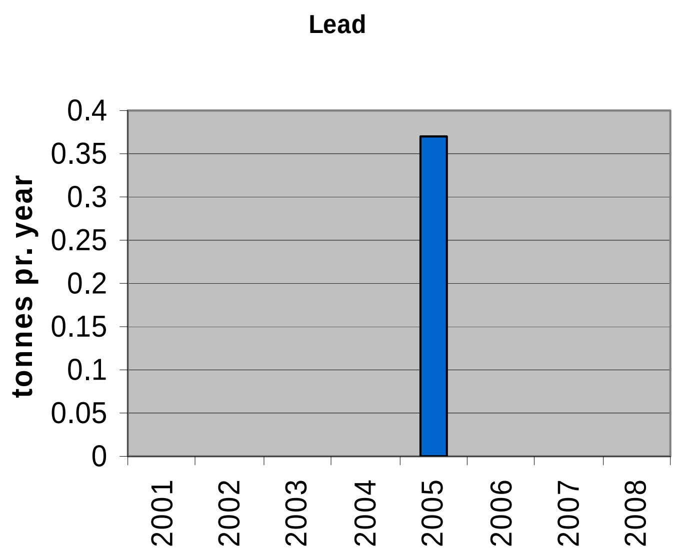


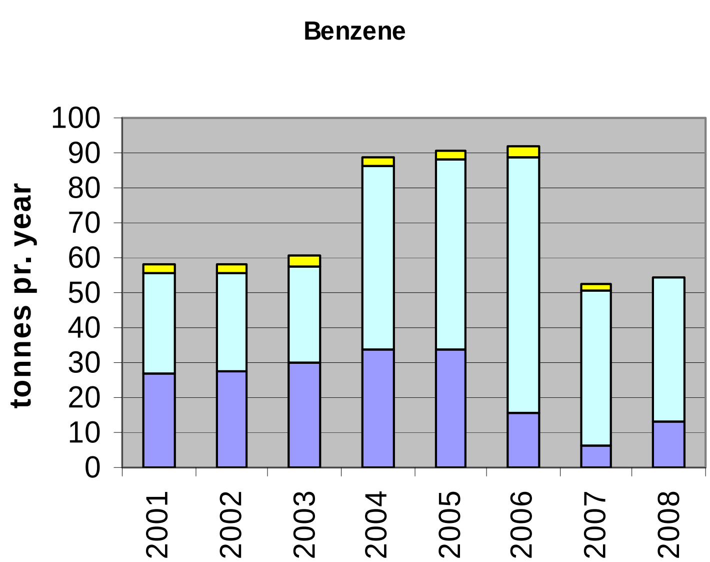

**PAH**



*Continued*

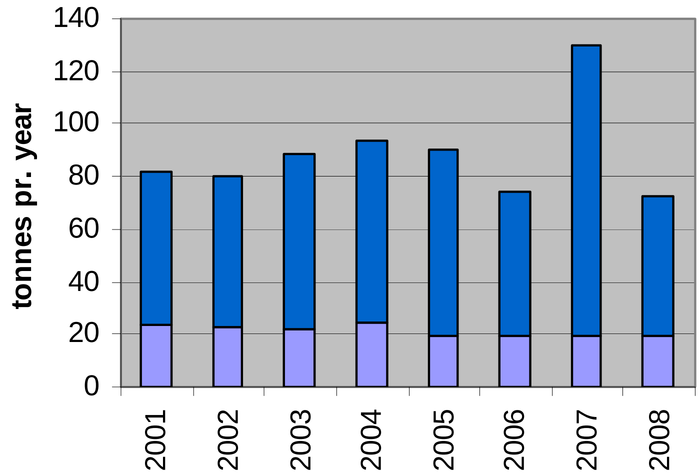


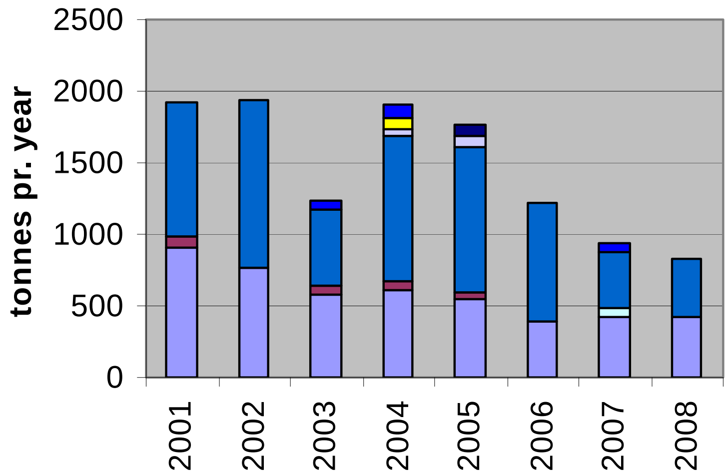




*Continued*

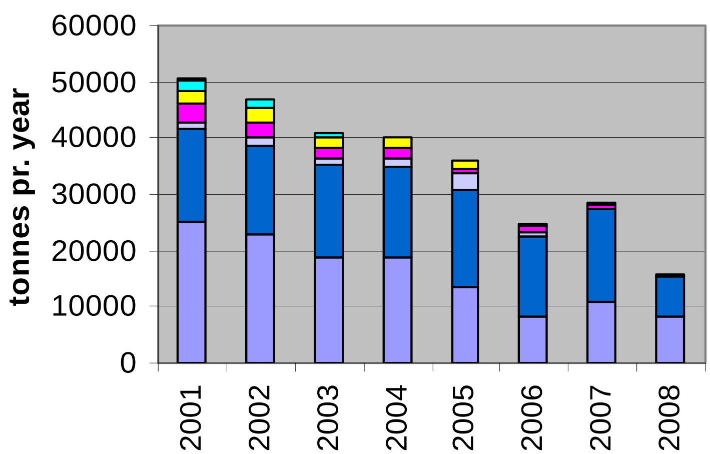
**Chlorine and its inorganic compounds**




**PM10**




**SOx/SO2**




*Continued*

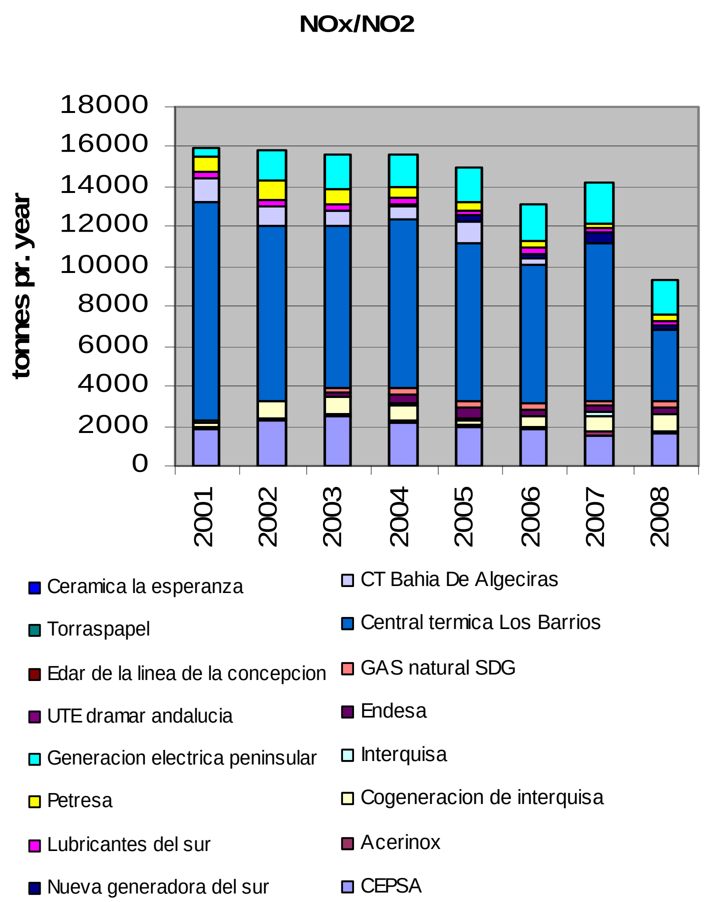



Figure 3.2 Time-trends in PRTR emission rates of pollutants from industries in Bay Area in tonnes pr. year. The pollutants are critical with respect to modelled air concentrations at Rosia Roads in relation to cancer and air quality threshold values. The first six are carcinogens and the last four are co-carcinogens.

### Modeled air concentrations in Gibraltar

#### EU Technical Guidance Document (TGD)

The modelling in this study is performed according to the EU Technical Guidance Document (TGD). The TGD supports legislation on assessment of risks of chemical substances to human health and the environment. Of special relevance to this study the TGD gives advice on how to calculate Predicted Environmental Concentrations (PECs) and, where this is not possible, how to make qualitative estimates of environmental concentrations. Chemical substances are hereafter termed pollutants.

In order to ensure that the PECs are realistic, all available exposure-related information on the pollutants should be used. A general rule for deriving PECs is that the best and most realistic information available should be given preference. However, it may often be useful to initially conduct an exposure assessment based on worst-case assumptions, and using default values when model calculations are applied. Such an approach can also be used in the absence of sufficiently detailed data. If the outcome of the risk characterisation based on worst-case assumptions for the exposure is that the pollutant is not “of concern”, the risk assessment for that pollutant can be stopped with regard to the compartment considered. If, in contrast, the outcome is that a pollutant is “of concern”, the assessment must, if possible, be refined using a more realistic exposure prediction.

The exposure levels should be evaluated for both measured data, if available, and model calculations. Preference should be given to adequately measured, representative and liable data where these are available.

For the emission estimates of pollutants a distinction is usually made between pollutants that are emitted through point sources, e.g. industries, to which a specific location can be assigned and pollutants that enter the environment through diffuse emissions, e.g. household emissions and traffic. Point sources primarily impact on the local environment but also contribute on a larger, i.e. regional, scale. PECs of pollutants emitted from point sources are assessed for a generic local environment. This is a hypothetical site with predefined, agreed environmental characteristics, the so-called standard environment. Concentrations of pollutants emitted from point and diffuse sources over a wider area are assessed for a generic regional environment.

According to the TGD the local PEC in air from a point source emission is found from the Gaussian plume model OPS, Van Jaarsveld (1992) using the standard parameters described by Toet and de Leeuw (1992). The model builds on the following assumptions:

- Air concentration at a distance of 100 meters from the point source, which is chosen to represent the average distance between the emission source and the border of the industrial site, are calculated.
- Average atmospheric conditions are used, obtained from a 10-year data set of weather conditions for the Netherlands.
- The atmospheric reaction rate is set at 5 % per hour. However, on the regarded spatial scale, atmospheric reactions are negligible (Toet & de Leeuw, 1992).
- Losses due to deposition are neglected.
- Assumed source characteristics:
  - Source height = 10 m representing height of buildings.
  - Heat content of emitted gas: 0, which assumes no extra plume rise (conservative approach).
  - Source area: 0 meters, representing an ideal point source.
- Calculated concentrations are long term values.

In the TGD a number of calculations were carried out to describe a relationship between the characteristics of pollutants and the local PEC and it was concluded that local PEC is independent of the physico-chemical properties of the pollutants. Hence, once the emission rate from a point source is known, the concentration in air (PEClocal-air) at a distance of 100 meter from the source can be estimated from a simple linear relationship:

PEClocal-air = max(Elocal-air)* Cstd-air (mg/m$^3$) (Equation 1)

Where;

- Elocal-air is the local emission rate to air in kg/day.

- Cstd-air = $2.78*10^{-4}$ mg/m$^3$ is the concentration in air at a source strength of 1 kg/day.

As an example the TGD approach is used for calculating PEClocal-air for PAHs in 2008. Only the CEPSA refinery has reported a PAH emission rate in 2008, of 668 kg/year (Table 3.7 page 32-33):

PEClocal-air = $668/365*2.78*10^{-4}$ = 510 ngPAH/m$^3$

In comparison the measured annual mean concentration at Rosia Road in 2008 is 0.07 ng/m$^3$. However, in the Gibraltar monitoring programme PAH is represented by benzo(a)pyrene, whereas under PRTR, where the CEPSA emission is reported, six PAHs are included. In urban air the benzo(a)pyrene concentration is typically in the range 0.3 – 2 ng/m$^3$, which constitutes approximately 1.4 % of the total PAH concentration of 20 – 150 ng/m$^3$ (EC, 2001; Coleman et al., 1997; US-EPA, 2010; Broman et al., 1991; Hoff & Chan, 1987). The measured B(a)P concentration thus corresponds to an approximate total PAH concentration in Gibraltar of 5.2 ng/m$^3$. Although the TGD represents a conservative estimate it overestimates the local PAH in air concentration considerably. The TGD approach is not appropriate to the specific conditions on a number of accounts, most importantly:

- The distances from industries to the monitoring station exceed 100 m, typically > 5 km.
- Local atmospheric conditions deviate considerably from Dutch conditions.
- Source heights deviate from 10 m, typically 30 to 70 m.

In order to perform a realistic, transparent and accurate prediction of the local air concentrations derived from the emission rates of industries in the Bay Area and adjacent municipalities it was decided to modify the TGD approach and use a modelling approach where the above points were addressed.

#### OML-Multi modelling

The OML-Multi is, like the OPS model, a multi source version of the atmospheric Gaussian plume dispersion model OML (Olesen et al., 2009, 2007a, 2007b). It is used to assess air pollution from point and area sources and can be used at distances up to around 20 km from the source, which correspond to local conditions. It has been developed by the Department of Atmospheric Environment at the National Environmental Research Institute (NERI) – Aarhus University in Denmark. The model is a part of the Danish regulatory Guidelines on air quality and is applied for e.g. environmental impact assessment when new industrial installations are planned or to demonstrate that planned facilities comply with the Guidelines. Furthermore the model can be used for environmental assessments, where air pollution needs to be mapped for a designated area.

Local conditions are defined at distances below 20 km, and regional at distances larger than 20 km. The point sources and municipal area sources considered here are thus all at a local scale. The model can be used for high and low sources in flat or moderately sloping terrain. Information on emission and meteorology on an hourly basis is normally used; however, in this case annual mean emissions are applied. Meteorology data are obtained from the meteorological model MM5 (Grell et al. 1995) implemented in the Danish Integrated Air Pollution Forecasting System THOR (Brandt et al. 2007) and based on global 3D meteorological data every six hour from NCEP, USA. Sea breezes, i.e. locally generated southerly winds overlaying the regional scale general wind directions from either east or west, are not accounted for in the model due to the coarse grid in the regional meteorological model MM5, this implies that there is an overrepresentation of exposure from the point and area sources and consequently gives a conservative estimate of the air concentration in Gibraltar. When ship traffic in the Strait is included it is necessary to include sea breezes. Point sources are applied in UTM coordinates and municipalities are applied as area sources in a 2x2 $km^2$ grid with constant and evenly distributed emission rate in each grid area. The output of the model is annual mean concentrations of pollutants at Rosia Road monitoring station. The model setup with marked point sources and grid for area sources is shown in Figure 3.3.

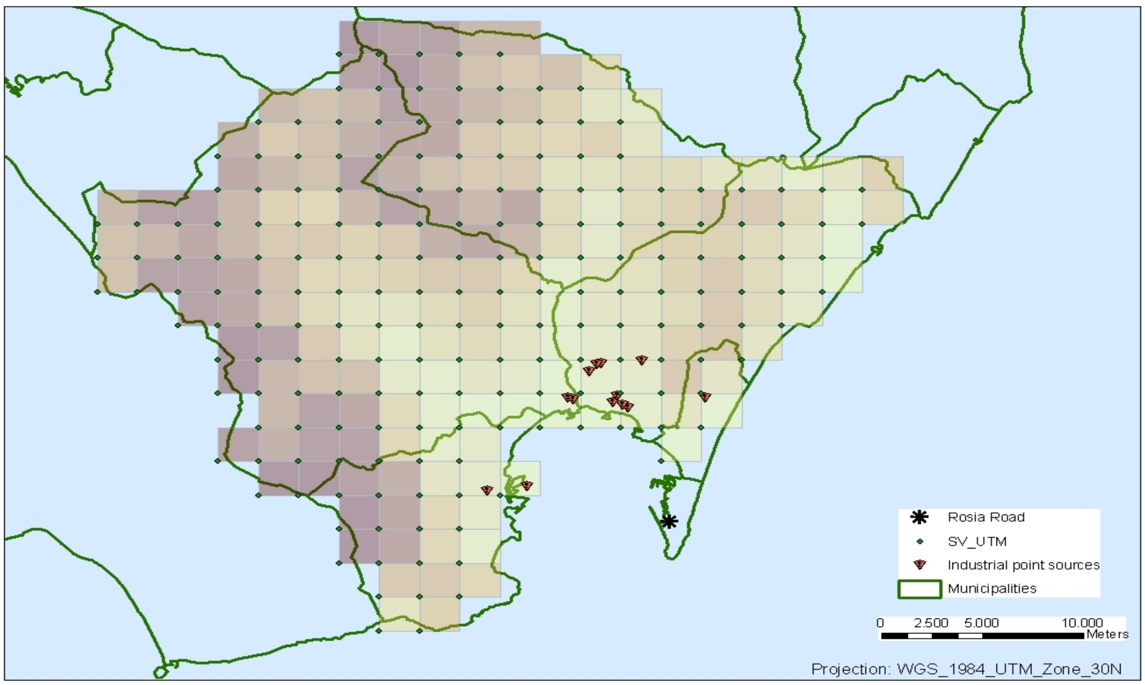



Figure 3.3 Industrial point sources in Bay Area and 2x2 $km^2$ grid representing five most adjacent municipalities with evenly distributed emission rates in each municipality and corresponding grid points of the south-west corner of the grid cells. Colours in grids show sloping of terrain.

The plume dispersion from industrial emissions depends on the stack height and the smoke plume rise. Plume rise is determined by exit velocity, volume and temperature. However, these parameters are not available for most of the industrial facilities. Therefore a sensitivity analysis has been done in order to obtain a realistic and conservative estimate of calculated concentrations.

For 2005 to 2009 meteorology data the influence on air concentration at Rosia Road was investigated with the following parameter ranges for industrial point sources:

- Stack height 10 – 100 m.
- Exit velocity 0.0 – 20 m/s.

- Exit volume 0.1 – 30 $Nm^3/s$.
- Exit temperature 20 – 50°C.

And for municipal diffuse area sources:

- Emission height 10 – 50 m

From the sensitivity analysis the following parameter values are found for industrial point sources:

- Stack height 30 m.
- Exit velocity 0.2 m/s.
- Exit volume 0.1 $Nm^3/s$.
- Exit temperature 20°C.

And for municipal diffuse area sources:

- Emission height 10 m.

These values are used in the OML-Multi modelling to establish conservative and realistic air concentrations at Rosia Road.

**Results**

OML-Multi model calculations of pollutant air concentrations in 2005 and 2008 at Rosia Road from reported industrial PRTR emission rates are shown below in Table 3.8 and 3.10, respectively. OML-Multi model calculations of pollutant air concentrations in 2005 at Rosia Road from municipal diffuse emissions are shown below in Table 3.9.

Given the assumptions in the model set-up the OML-Multi model is tested towards the TGD calculation and the measurements made in Gibraltar. The modelled annual mean air concentration for PAHs from CEPSA emissions in 2008 with the OML model is 2.1 $ng/m^3$ (Table 3.10). The extrapolated measured total PAH concentration of 5.2 $ng/m^3$, as derived previously, is a factor of 2.5 higher. The data input and model set-up of OML-Multi provides a conservative estimate and with the methodological improvements it gives a higher accuracy and reliability compared to the TGD approach. Modelled and measured concentrations of other pollutants are compared in Table 3.11 page 47.

Table 3.8 OML-Multi model calculations of pollutant air concentrations (µg/m$^3$) in 2005 at Rosia Road from reported industrial PRTR emission rates.

| Pollutant | CEPSA | Acerinox | Cogeneracion de interquisa | Interquisa | Endesa | GAS natural SDG | Central termica Los Barrios | CT Bahia De Algeciras |
|---|---|---|---|---|---|---|---|---|
| Chlorine and its inorganic compounds | 0.056 | - | - | - | - | - | 0.19 | - |
| $PM_{2.5}$ | | | | | | | | |
| $PM_{10}$ | 1.6 | 0.13 | - | - | - | - | 2.7 | 0.23 |
| Particles (unspecified) | | | | | | | | |
| Arsenic | 0.000066 | - | - | - | - | - | - | 0.000075 |
| Cadmium | 0.000085 | - | - | - | - | - | - | - |
| Chromium | 0.0057 | 0.0013 | - | - | - | - | 0.00064 | - |
| Lead | - | - | - | - | - | - | 0.00099 | - |
| Mercury | 0.000068 | - | - | - | - | - | - | - |
| Nickel | 0.021 | 0.00027 | - | - | - | - | 0.00082 | 0.0048 |
| NMVOC (unspecified) | 3.7 | - | - | 3.1 | - | - | - | - |
| Benzene | 0.096 | - | - | 0.12 | - | - | - | - |
| Hexachlorobenzene | - | - | - | - | - | - | - | - |
| Hexachlorocyclohexane (Lindane) | - | - | - | - | - | - | - | - |
| PCDD/F (dioxins unspecified) | - | - | - | - | - | - | - | - |
| Tetrachloroethylene | - | - | - | - | - | - | - | - |
| Trichloroethylene | - | - | - | - | - | - | - | - |
| Trichloromethane | - | - | - | - | - | - | - | - |
| $SO_x$ (/$SO_2$ for PRTR data) | 38 | - | - | - | - | - | 46 | 8.5 |
| $NO_x$ (/$NO_2$ for PRTR data) | 5.5 | 0.29 | 0.62 | 0.28 | 1.2 | 0.58 | 21 | 3.0 |
| PAH[1)] | 0.0028 | - | - | 0.018 | - | - | - | - |

[1)] PRTR: six species, monitoring: B(a)P.

blank: not reported.

-: emissions below reporting threshold.

Table 3.8 (*continued*) OML-Multi model calculations of pollutant air concentrations (µg/m$^3$) in 2005 at Rosia Road from reported industrial PRTR emission rates.

| Pollutant | Nueva generadora del sur | Lubricantes del sur | Petresa | Generacion electrica peninsular | UTE dramar andalucia | Edar de la linea de la concepcion | Torraspapel | Ceramica la esperanza |
|---|---|---|---|---|---|---|---|---|
| Chlorine and its inorganic compounds | - | - | - | - | - | - | - | - |
| $PM_{2.5}$ | | | | | | | | |
| $PM_{10}$ | 0.24 | - | - | - | - | - | - | - |
| Particles (unspecified) | | | | | | | | |
| Arsenic | - | - | - | - | - | - | - | - |
| Cadmium | - | - | - | - | - | - | - | - |
| Chromium | - | - | - | - | - | - | - | - |
| Lead | - | - | - | - | - | - | - | - |
| Mercury | - | - | - | - | - | - | - | - |
| Nickel | - | 0.0035 | 0.00057 | - | - | - | - | - |
| NMVOC (unspecified) | - | 0.95 | - | - | | - | - | - |
| Benzene | - | - | 0.0065 | - | - | - | - | - |
| Hexachlorobenzene | - | - | - | - | - | - | - | - |
| Hexachlorocyclohexane (Lindane) | - | - | - | - | - | - | - | - |
| PCDD/F (dioxins unspecified) | - | - | - | - | - | - | - | - |
| Tetrachloroethylene | - | - | - | - | - | - | - | - |
| Trichloroethylene | - | - | - | - | - | - | - | - |
| Trichloromethane | - | - | - | - | - | - | - | - |
| $SO_x$ (/$SO_2$ for PRTR data) | - | 3.2 | 3.5 | - | - | - | - | - |
| $NO_x$ (/$NO_2$ for PRTR data) | 1.1 | 0.65 | 1.2 | 3.3 | - | - | - | - |
| PAH[1)] | - | - | - | - | - | - | - | - |

[1)] PRTR: six species, monitoring: B(a).

blank: not reported.

-: emissions below reporting threshold.

Table 3.9 OML-Multi model calculations of pollutant air concentrations (µg/m$^3$) in 2005 at Rosia Road from municipal diffuse emissions.

| Pollutant | Algeciras | Castellar De La Frontera | La Linea De La Concepcion | Los Barrios | San Roque |
|---|---|---|---|---|---|
| Chlorine and its inorganic compounds | 0.000073 | 0 | 0.000051 | 0.000052 | 0.027 |
| $PM_{2.5}$ | 0.93 | 0.017 | 0.23 | 0.67 | 0.93 |
| $PM_{10}$ | 0.95 | 0.018 | 0.27 | 0.1 | 0.15 |
| Particles (unspecified) | 0.98 | 0.023 | 0.32 | 9.9 | 2.9 |
| Arsenic | 0.000044 | 0.000000013 | 0.00000046 | 0.0000021 | 0.000057 |
| Cadmium | 0.0000057 | 0.000000038 | 0.0000024 | 0.0000091 | 0.000073 |
| Chromium | 0.000033 | 0.00000031 | 0.000019 | 0.0000029 | 0 |
| Lead | 0.000087 | 0.000003 | 0.000037 | 0.00012 | 0.00049 |
| Mercury | 0.0000047 | 0 | 0.0000012 | 0.00046 | 0.000018 |
| Nickel | 0.0025 | 0.00000035 | 0.00049 | 0.0000025 | 0 |
| NMVOC (unspecified) | 7.9 | 1 | 3.8 | 4.1 | 5.2 |
| Benzene | 0.076 | 0 | 0 | 0.0017 | 0.018 |
| Hexachlorobenzene | 0.000000055 | 0.0000025 | 0.000032 | 0.000029 | 0.0000053 |
| Hexachlorocyclohexane (Lindane) | 0.000000055 | 0.0000039 | 0.000052 | 0.0000012 | 0.0000084 |
| PCDD/F (dioxins unspecified) | 0.00000000057 | 0.000000000013 | 0.00000000015 | 0.00000000014 | 0.00000000015 |
| Tetrachloroethylene | 10 | 0.19 | 16 | 1.8 | 2.8 |
| Trichloroethylene | 12 | 0.23 | 19 | 2.2 | 3.3 |
| Trichloromethane | 0 | 0 | 0 | 0 | 0.00046 |
| $SO_x$ (/$SO_2$ for PRTR data) | 5.9 | 0.0024 | 0.14 | 0.069 | 1.1 |
| $NO_x$ (/$NO_2$ for PRTR data) | 9.3 | 0.1 | 1.2 | 0.7 | 0 |
| PAH (unspecified) | 0.0001 | 0.0000085 | 0.0002 | 0.000051 | 0.00022 |

0: reported emission zero.

Table 3.10 OML-Multi model calculations of pollutant air concentrations (µg/m$^3$) in 2008 at Rosia Road from reported industrial PRTR emission rates.

| Pollutant | CEPSA | Acerinox | Cogeneracion de interquisa | Interquisa | Endesa | GAS natural SDG | Central termica Los Barrios | CT Bahia De Algeciras |
|---|---|---|---|---|---|---|---|---|
| Chlorine and its inorganic compounds | 0.062 | - | - | - | - | - | 0.15 | - |
| $PM_{2.5}$ | | | | | | | | |
| $PM_{10}$ | 1.4 | - | - | - | - | - | 1.2 | - |
| Particles (unspecified) | | | | | | | | |
| Arsenic | 0.000073 | - | - | - | - | - | - | - |
| Cadmium | 0.000073 | - | - | - | 0.000032 | - | - | - |
| Chromium | 0.0063 | 0.00071 | - | - | - | - | - | - |
| Lead | - | - | - | - | - | - | - | - |
| Mercury | - | - | - | - | - | - | 0.000053 | - |
| Nickel | 0.023 | - | - | - | - | - | - | - |
| NMVOC (unspecified) | 1.3 | - | - | 2.3 | - | - | - | - |
| Benzene | 0.041 | - | - | 0.1 | - | - | - | - |
| Hexachlorobenzene | - | - | - | - | - | - | - | - |
| Hexachlorocyclohexane (Lindane) | - | - | - | - | - | - | - | - |
| PCDD/F (dioxins unspecified) | - | - | - | - | - | - | - | - |
| Tetrachloroethylene | - | - | - | - | - | - | - | - |
| Trichloroethylene | - | - | - | - | - | - | - | - |
| Trichloromethane | - | - | - | - | - | - | - | - |
| $SO_x$ (/$SO_2$ for PRTR data) | 26 | - | - | - | - | - | 20 | - |
| $NO_x$ (/$NO_2$ for PRTR data) | 5.2 | 0.42 | 1.9 | - | 0.83 | 0.79 | 11 | - |
| PAH[1)] | 0.0021 | - | - | - | - | - | - | - |

[1)] PRTR: six species, monitoring: B(a)P.

blank: not reported.

-: emissions below reporting threshold.

Table 3.10 (continued) OML-Multi model calculations of pollutant air concentrations (µg/m³) in 2008 at Rosia Road from reported industrial PRTR emission rates.

| Pollutant | Nueva generadora del sur | Lubricantes del sur | Petresa | Generacion electrica peninsular | UTE dramar andalucia | Edar de la linea de la concepcion | Torraspapel | Ceramica la esperanza |
|---|---|---|---|---|---|---|---|---|
| Chlorine and its inorganic compounds | - | - | - | - | - | - | - | - |
| $PM_{2.5}$ | | | | | | | | |
| $PM_{10}$ | - | - | - | - | - | - | - | - |
| Particles (unspecified) | | | | | | | | |
| Arsenic | - | - | - | - | - | 0.000020 | - | - |
| Cadmium | - | - | - | - | - | - | - | - |
| Chromium | - | - | - | - | - | - | - | - |
| Lead | - | - | - | - | - | - | - | - |
| Mercury | - | - | - | - | - | - | - | - |
| Nickel | - | 0.0033 | - | - | - | - | - | - |
| NMVOC (unspecified) | - | - | - | - | - | - | - | - |
| Benzene | - | - | - | - | - | - | - | - |
| Hexachlorobenzene | - | - | - | - | - | - | - | - |
| Hexachlorocyclohexane (Lindane) | - | - | - | - | - | - | - | - |
| PCDD/F (dioxins unspecified) | - | - | - | - | - | - | - | - |
| Tetrachloroethylene | - | - | - | - | - | - | - | - |
| Trichloroethylene | - | - | - | - | - | - | - | - |
| Trichloromethane | - | - | - | - | - | - | - | - |
| $SO_x$ (/$SO_2$ for PRTR data) | - | 2.2 | - | - | - | - | - | - |
| $NO_x$ (/$NO_2$ for PRTR data) | 0.7 | 0.5 | 0.99 | 4.6 | - | - | - | - |
| PAH[1)] | - | - | - | - | - | - | - | - |

[1)] PRTR: six species, monitoring: B(a)P.

blank: not reported.

-: emissions below reporting threshold.

In Table 3.11 columns two, three and four OML-Multi modelled annual mean air concentrations at Rosia Road in 2005 and 2008 are shown from summed industrial and municipal emissions. Monitored annual mean air concentrations in 2008 are shown in column five. When a pollutant is measured at more locations than one, the maximum measured concentration is shown. To evaluate the comparability of OML-Multi modelled annual mean air concentrations and monitored annual mean air concentrations a deviation factor is introduced in column six. The deviation factor is defined as modelled concentration divided by monitored concentration. When the deviation factor is >1, the modelled value exceeds the monitored value and reversely when the deviation factor <1. A deviation factor of 1 indicates identical modelled and measured air concentrations. Deviation factors are calculated for 2008, which is the most recent year of emission reporting. In the last column pollutant threshold values, i.e. 1:10.000 risk concentrations for carcinogens and air quality guideline values for other pollutants are shown. These are used for assessing whether monitored and modelled pollutant concentrations are critical with respect to cancer, cf. summary in Table 4.1 page 84.

Table 3.11 OML-Multi modelled annual mean air concentrations at Rosia Road in µg/m³ in 2005 and 2008. Monitored annual mean air concentrations in µg/m³ in 2008. When a pollutant is measured at more locations than one, the maximum concentration is shown. Deviation factors are modelled concentrations in 2008 divided by monitored concentrations in 2008. Threshold values are 1:10.000 risk concentrations for carcinogens and air quality guideline values for other pollutants

| | Municipalities 2005 | Industries 2005 | Modelled Industries 2008 | Monitored 2008 | Deviation factor 2008 | Threshold values[2)] |
|---|---|---|---|---|---|---|
| Chlorine and its inorganic compounds | 0.027 | 0.24 | 0.022 | / | / | RfC = 0.2 µg/m³ WHO (no IARC class) |
| $PM_{2.5}$ | 2.8 | | | 15 | | WHO: 10 µg/m³ annual mean; 25 µg/M3 24 hr mean - lung |
| $PM_{10}$ | 1.5 | 4.9 | 2.5 | 41 | 0.06 | WHO: 20 µg/m³ annual mean; 50 µg/m³ 24 hr mean - lung |
| Particles (unspecified) | 14 | | | / | / | NA |
| Arsenic | 0.0001 | 0.00014 | 0.000093 | 0.0012 | 0.07 | 1 in 10.000 = 0.02 µg/m³ (IARC class 1) - lung |
| Cadmium | 0.00009 | 0.000085 | 0.00011 | 0.0002 | 0.6 | 1 in 10.000 = 0.06 µg/m³ (IARC class 1) - lung |
| Chromium | 0.000055 | 0.0076 | 0.007 | / | / | 1 in 10.000 = 0.0025 µg/m³ (IARC class 1 Cr 6 and 3 for others) – lung |
| Lead | 0.00073 | 0.00099 | - | 0.011 | - | IARC class 2A-3 |
| Mercury | 0.00048 | 0.000068 | 0.000053 | / | / | RfC = 1 µg/m³ WHO (no IARC class) |
| Nickel | 0.003 | 0.031 | 0.027 | 0.02 | 1.3 | 1 in 10.000 = 0.25 µg/m³ (IARC class 1) – lung |
| NMVOC (unspecified) | 22 | 7.8 | 3.6 | / | / | IARC class 3 |
| Benzene | 0.096 | 0.22 | 0.14 | 2.2 | 0.06 | 1 in 10.000 = 13 µg/m³ (IARC class 1) - leukaemia |
| Hexachlorobenzene | 0.00007 | - | - | / | / | 1 in 10.000 = 0.2 µg/m³ (IARC class 2B) |
| Hexachlorocyclohexane (Lindane) | 0.000065 | - | - | / | / | 1 in 10.000 = 0.06 µg/m³ (IARC class 2B) |
| PCDD/F (dioxins unspecified) | 0.000000001 | - | - | / | / | 1 in 10.000 = 0.00008 µg/m³ (IARC class 1) |
| Tetrachloroethylene | 31 | - | - | / | / | RfC = 250 µg/m³ (IARC class 2A) |
| Trichloroethylene | 37 | - | - | / | / | 1 in 10.000 = 230 µg/m³ (IARC class 2A) |
| Trichloromethane | 0.00046 | - | - | / | / | 1 in 10.000 = 4 µg/m³ (no IARC class) |
| $SO_x$ (/$SO_2$ for PRTR data) | 7.2 | 100 | 49 | 11 | 5 | WHO: 20 µg/m3 24 hr; 500 µg/m³ 10 min mean (IARC class 3 $SO_2$) |
| $NO_x$ (/$NO_2$ for PRTR data) | 11 | 39 | 26 | 61 | 0.4 | WHO: 40 µg/m³ annual mean; 200 µg/m³ 1 hr mean (no IARC class) |
| PAH[1)] | 0.00058 | 0.021 | 0.0021 | 0.0052 | 0.4 | B(a)P: 1 in 10.000 = 0.0012 µg/m³ (IARC class 1) |
| Ethyl benzene | | | | 2.3 | | NA |
| 1,3-butadiene | | | | 0.2 | | 1 in 10.000 = 3 µg/m³; leukaemia (IARC class 2) |
| Ozone | | | | 60 | | EAQG 120 µg/m³ max 8 hrs/day (no IARC class) |

[1)] total PAH; i.e. monitoring of 0.00007 µg B(a)P/m³ is extrapolated to 0.0052 µg total PAH/m³.

[2)] 1:10.000 risk concentrations for carcinogens and air quality guideline values for other pollutants. US.EPA IRIS and EAQG data used. The lowest value is used.

blank: emissions not reported.

-: emissions below reporting threshold.

/: not monitored.

NA: not applicable.

For Nickel and $SO_x$ /$SO_2$ the modelled concentrations are higher than the monitored concentrations (deviation factor > 1). For $PM_{10}$, arsenic, cadmium, benzene, total PAH and $NO_x$/$NO_2$ the monitored concentrations are higher (deviation factor < 1).

Deviation factors larger than one may be attributed to the omission of sea breezes, which gives a larger proportion of relatively more polluted air from land and industries. Deviation factors below one may be due to missing contribution from local road traffic, ships, local diesel generators and CEPSA flaring in Spain, which are important sources to particles, metals, PAH and VOCs. Even though important sources are not included and the deviation factor is below one for some pollutants the model set-up ensures conservative yet realistic estimates.

It is noted from the 2005 Figures in Table 3.11 (columns two and three) that except for mercury and unspecified NMVOCs the contribution to concentrations in air from industrial sources exceeds that from the diffuse sources from adjacent municipalities. Only one industry (CEPSA) has reported mercury emissions in 2005. Mercury emissions from municipalities are predominantly from production of electricity in Los Barrios. CEPSA, Interquisa and Lubricantes Del Sur have reported NMVOC emissions in 2005, whereas there are a variety of diffuse sources emitting NMVOCs in adjacent municipalities.

Table 3.11 shows a decrease in modelled annual mean air pollutant concentrations, except for cadmium, from industrial emissions between years 2005 and 2008 (columns three and four). This is reflected in the time-trends in emission rates from industries as shown in Figure 3.2 page 34-37.

The air concentrations in Table 3.11 are used to asses the cancer risk of the individual pollutants. Measured values (Table 3.11 column five) are compared with threshold values (Table 3.11 column seven). In section 5.1 page 81 we have listed and commented the co-carcinogens that exceed or are close to the threshold values. These are $SO_2$/$SO_x$, $NO_2$/$NO_x$, ozone, trichloromethane, ethylbenzene, chlorine and its inorganic compounds, $PM_{2.5}$ and $PM_{10}$. In section 5.2 page 83 this is done for the carcinogens, which are arsenic, chromium, lead, nickel, benzene, PAH, trichloroethylene, tetrachloroethylene and 1,3-butadiene.

For carcinogens tetrachloroethylene and trichloroethylene no monitored concentrations are available and the industrial PRTR emission rates are below reporting thresholds, therefore the modelled air concentrations found from reported 2005 emission rates from adjacent municipalities are used for risk assessment.

Carcinogen chromium is not included in the monitoring program; however, the modelled concentration derived from industrial and municipal emission rates are equal to the cancer threshold value.

Co-carcinogen mercury and carcinogens cadmium, PCDD/F, hexachlorobenzene and hexachlorocyclohexane have measured or modelled air concentrations that are significantly below their respective threshold values, and are therefore not considered further.

## 4.2 Cancer data analysis

As mentioned in the methods, the numbers of incident cancers are small in Gibraltar, which challenges international comparative analyses. Moreover, it is important to recognize that age structure plays a significant role in any country's incidence rate. Comparisons are also biased because some countries' published incidence rates are actually models based on cancer mortality rates. There are moreover also differences in expertise, experience and efficiency in generating cancer registrations between countries.

The Gibraltar cancer registry was revalidated before analysis. The revalidation process revealed that cancers requiring radiological diagnosis (for example lung and brain cancer) were not comprehensively covered in the registry prior to 2005, hence for these type of cancers and for total cancer only the data 2005-2009 is reliable and used in the analysis. In addition, up to 13% of the total files considered by the cancer registry as potential cancers that could unfortunately not be considered in the analysis as they remained uncertain with regards to whether or not they were cancers, or which types of cancers they might represent. These uncertain files were excluded from the cancer registry. All other factors being equal, it is reasonable to assume that any cancers remaining hidden in the uncertain files should have the same rate and distribution among cancers as the rest of the cancer registry.

For these reasons, when reviewing rates of the total cancers and of those cancers that require radiological diagnosis (in this case lung cancer) the main focus is on the period 2005-2009. For the remaining cancer types we look at the entire period 1999-2009.

### 4.2.1 Trends over time in Gibraltar cancer incidences

The trends in total cancers (excluding In Situ cancers and Non Melanoma Skin cancers) registered are shown below (Figure 3.4), where it is also obvious that the registration from 2005 and onwards has increased, primarily due to enhanced diagnostic certainty.

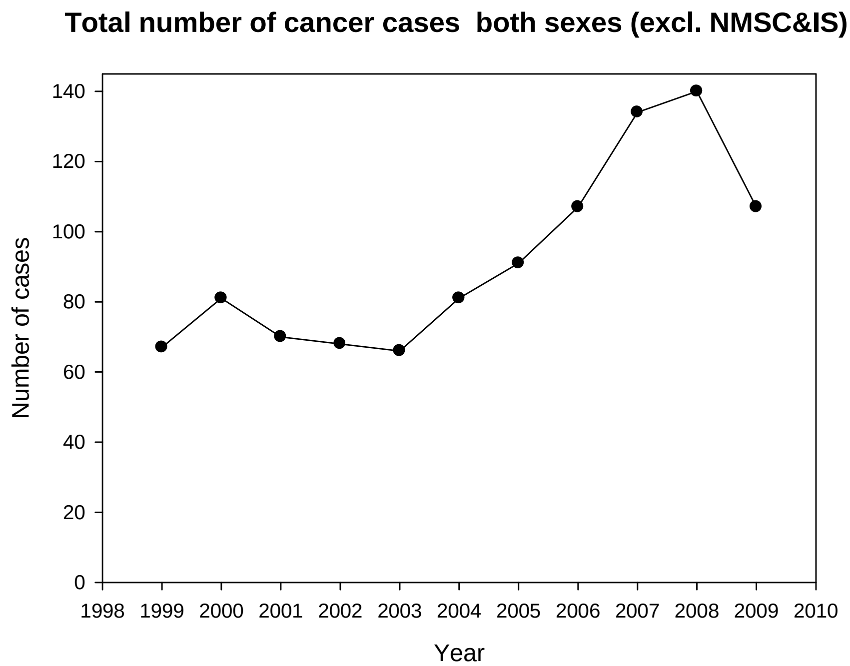


Figure 3.4 Trend in total cancers.

The trend in the total cancer incidence rate over time, depicted in the Figure 3.5 below varies between approx. 290 and 450.

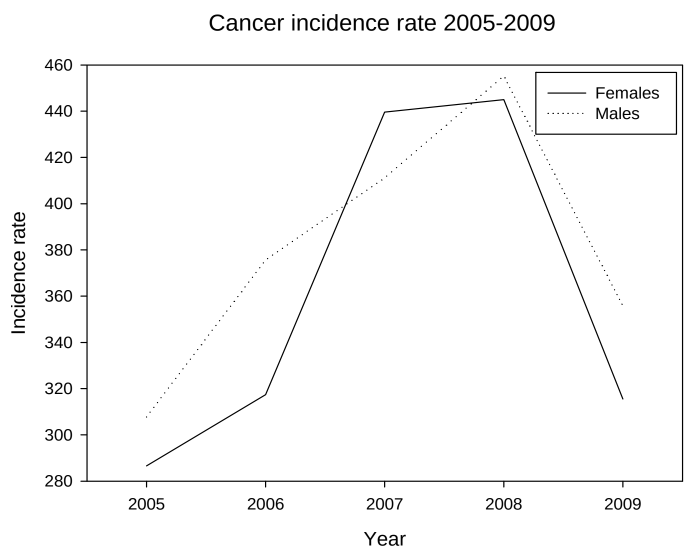


Figure 3.5 Incidence rate over time 2005-2009.

The cumulative life time risk of getting cancer in the Gibraltar population varies between 4 and 6 % (Figure 3.6), which is on par or below the developments elsewhere in the EU.

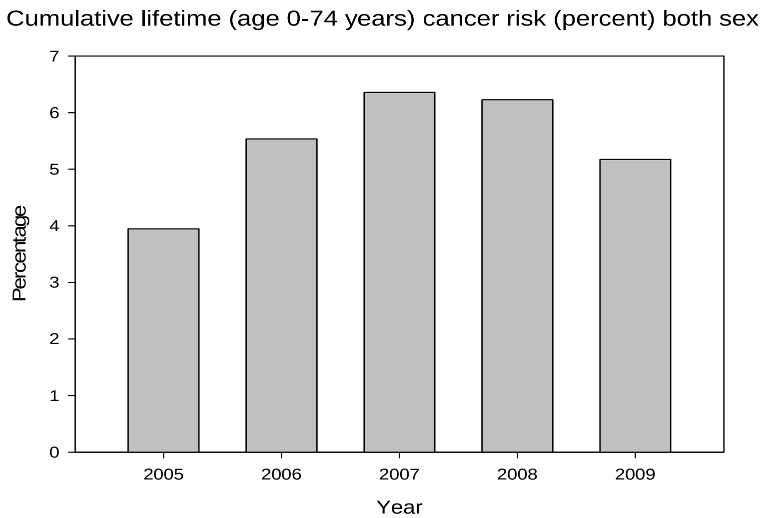



Figure 3.6 cumulative cancer risks.

The percentage distribution of cancer incidences over time for both sexes shows that breast cancer, colon and rectum, prostate, lung and bronchus, bladder, and corpus uteri are the most frequent cancer types representing >55 % of the total cancer incidences recorded (Figure 3.7).

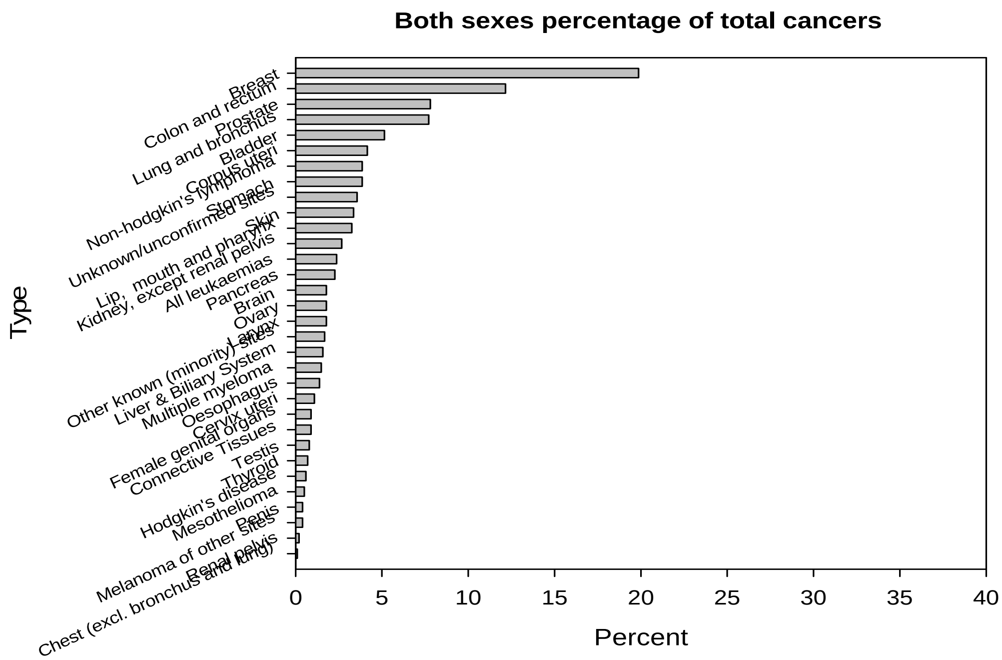



Figure 3.7 Distribution of cancers.

If we focus on the percentage distribution for females alone it is very clear that breast cancer is by far the most frequent cancer type representing more than 38 % of the total cancer incidences (Figure 3.8).

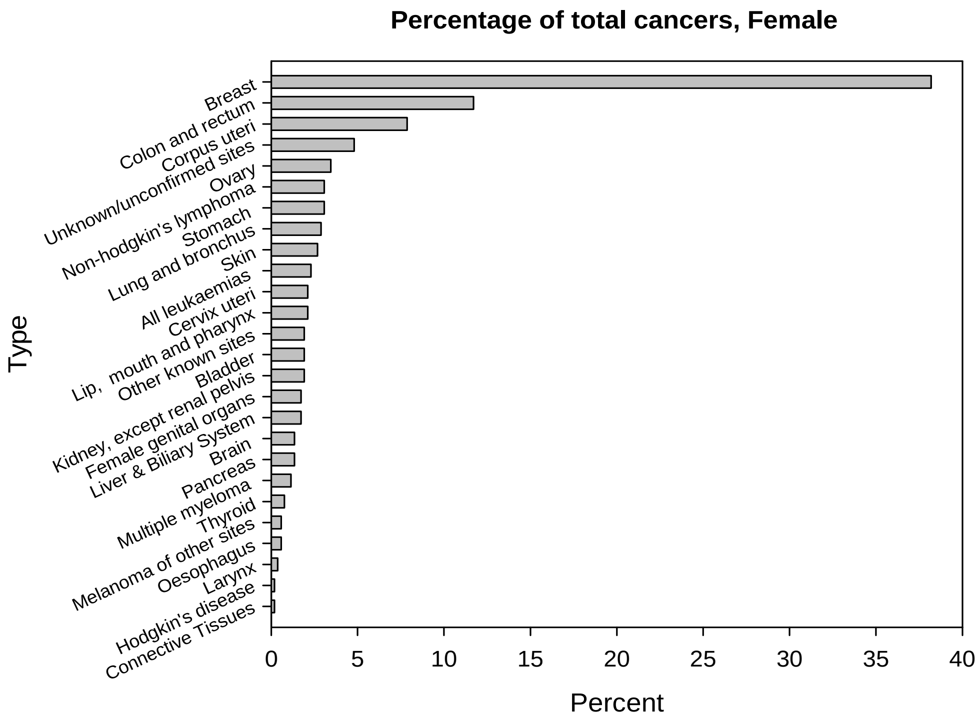



Figure 3.8 Distribution of cancers in females.

The incidence of cancer for males is of course different. Here the distribution of cancer types is more homogenous, with prostate, lung and bronchus, colon and rectum, and bladder as the most frequent cancer types. Their combined frequency is 50 % of the total cancers (Figure 3.9).

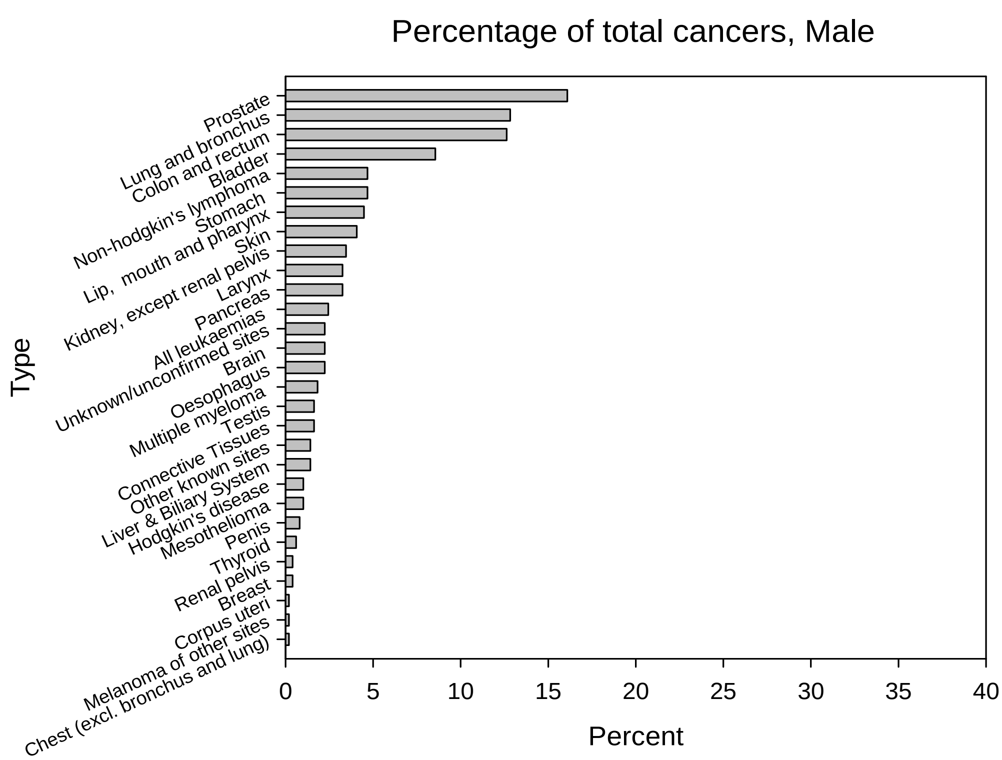



Figure 3.9 Distribution of cancers in males.

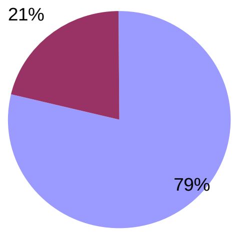
From a population and health perspective it is important to examine the distribution of cancers among different age groups. We already know that the cancer risk increases significantly with age especially 60+ years of age, so if the distribution in Gibraltar differs from this then that may trigger consideration of age specific exposure scenarios. Figure 3.11 shows the distribution of cancer incidences among age groups.

The distribution of cancer between the sexes within each cancer type is shown in Figure 3.10 below.

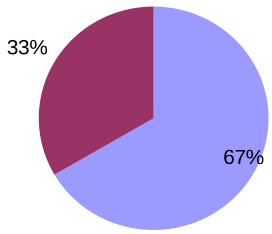
Males

Females

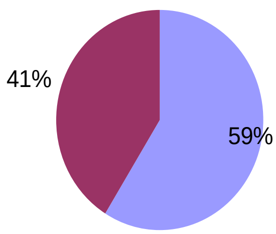
Oesophagus



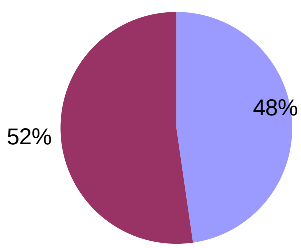

Lip, mouth and pharynx



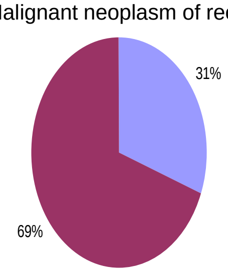

Stomach




Colon

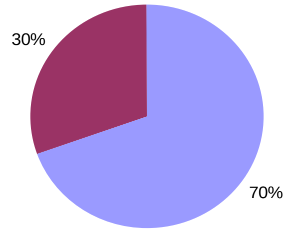



Malignant neoplasm of rectosigmoid junction

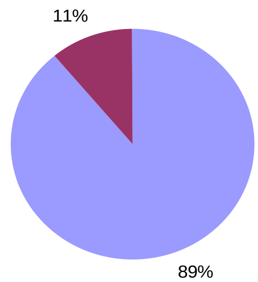



Malignant neoplasm of rectum

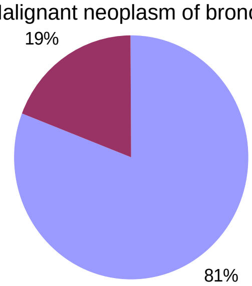
Malignant neoplasm of pancreas



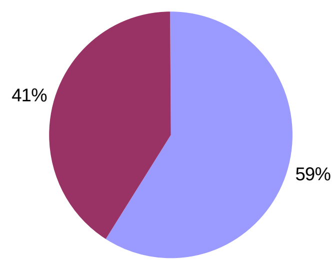

Malignant neoplasm of larynx



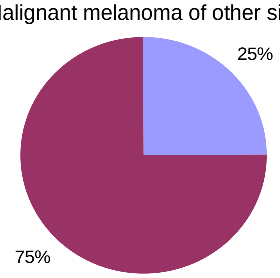

Malignant neoplasm of bronchus and lung



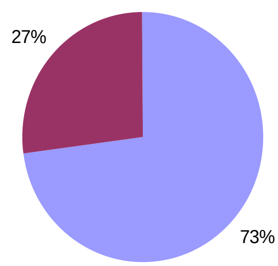

Malignant melanoma of skin



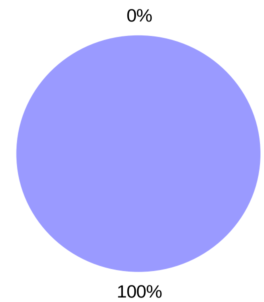

Malignant melanoma of other sights




Mesothelioma

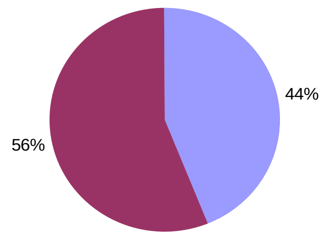



Malignant neoplasm of Liver & Biliary System

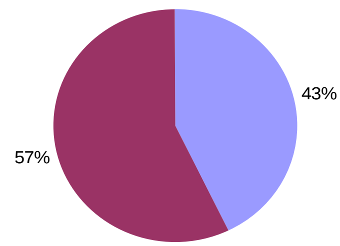



Malignant neoplasm of thyroid

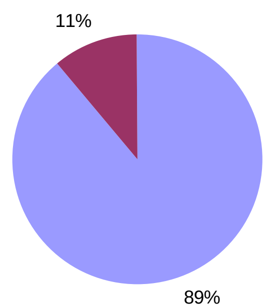
*Continued*



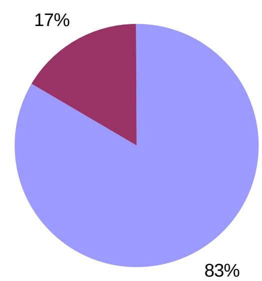

Malignant neoplasm of connective tissues



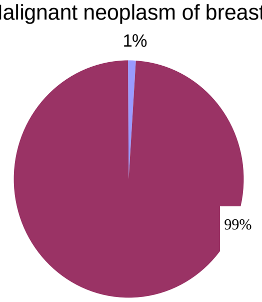

Hodgkin's disease



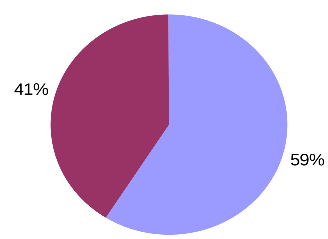

Malignant neoplasm of breast



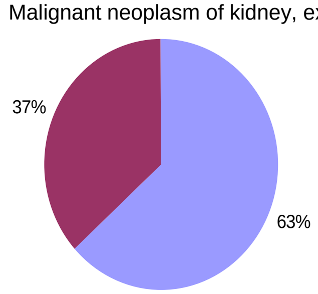

Non-Hodgkin's lymphoma



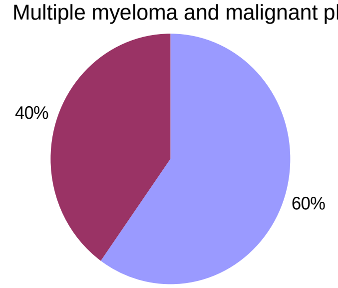

Malignant neoplasm of kidney, except renal pelvis




Multiple myeloma and malignant plasma cell neoplasms




Malignant neoplasm of bladder




All leukaemias

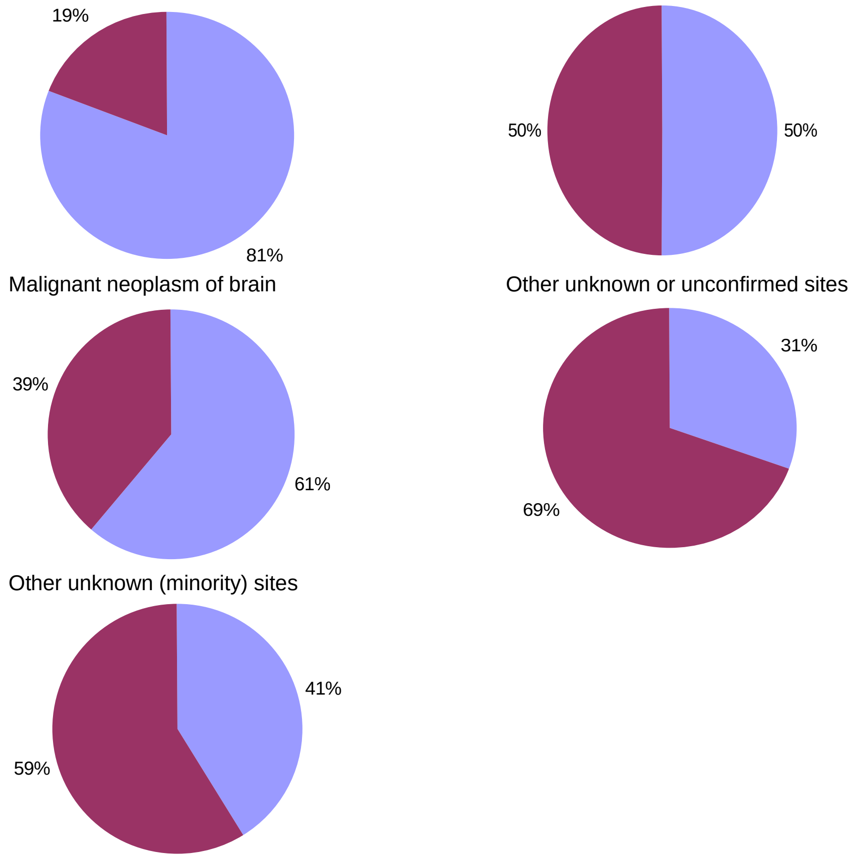



Figure 3.10 Cancer ratio between the sexes.

The distribution of cancers among age groups documents how the cancer risk increases with age and that there does not appear to be marked deviation from recorded cancers found elsewhere, i.e. that the cancer risk increases markedly (almost exponentially) with age typically around the age of sixty (Figure 3.11).

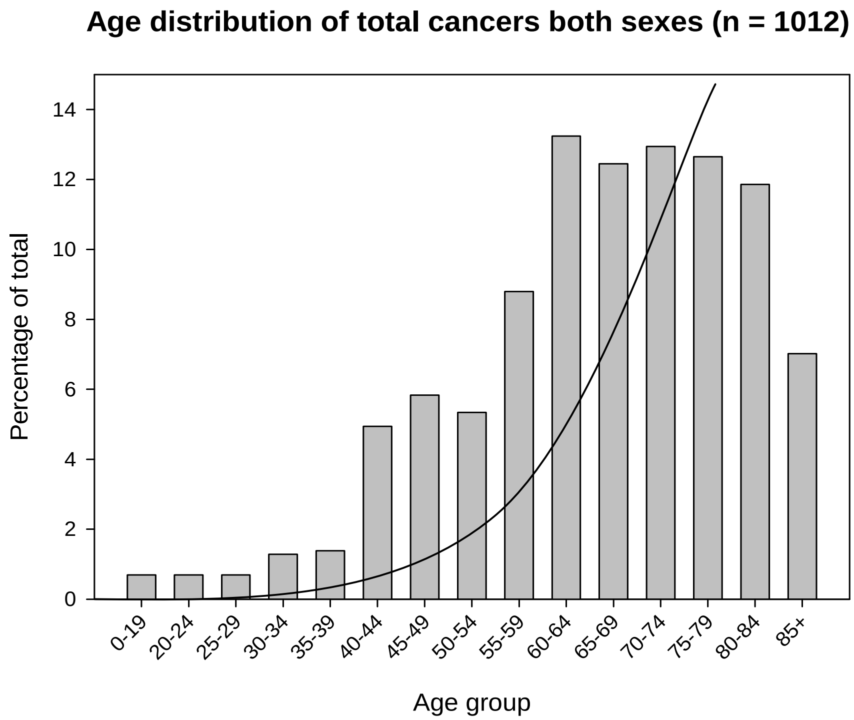



Figure 3.11 Age distribution of total cancer.

Most importantly there does not seem to be a general higher than expected childhood cancer risk, as they represent less than 1 % of the total cancer incidences.

The general age structure of a population is, all other factors being equal, the most determinant parameter for the cancer incidence rate. Figure 3.12 below shows the trend in the age structure since 1970 to 2001 in Gibraltar.

**Gibraltar demographics 1970-2001, both sexes**

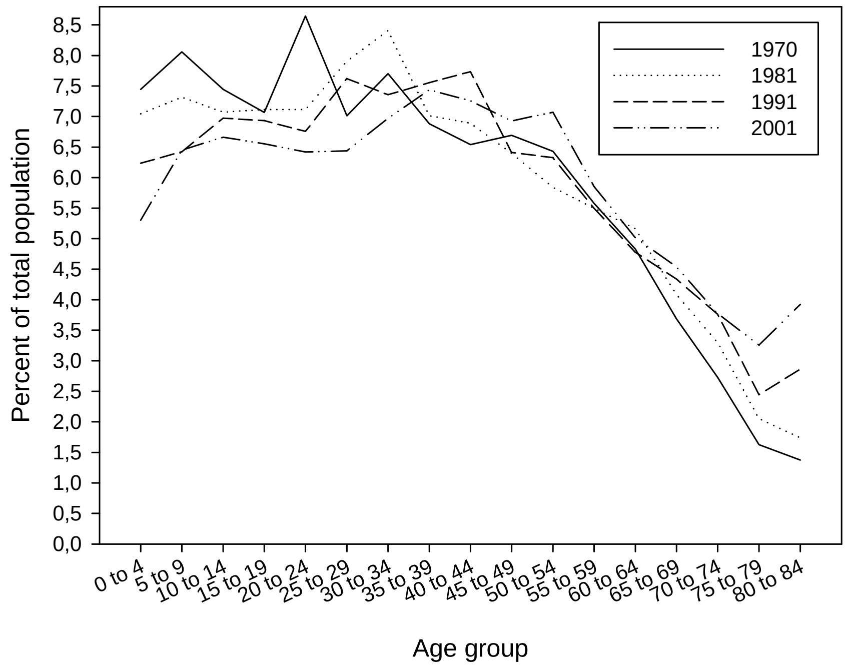



Figure 3.12 demographic trends 1970-2001.

These Census comparisons strikingly show that significant increases have occurred over time in the proportions of older people in the population. Counts of cancer numbers will only make sense if they are adjusted to take account of this variation as is done in the standardization of the cancer registry data. The important changes should be found in percentages of young vs. old. This is more evident if we normalise the data to the most recent census (2001) in Figure 3.13. An increase in the population above 60 years of age will, all other factors being equal, lead to increasing cancer incidence rates.

Proportion of agegroup in Gibraltar 1970-2001, both sexes

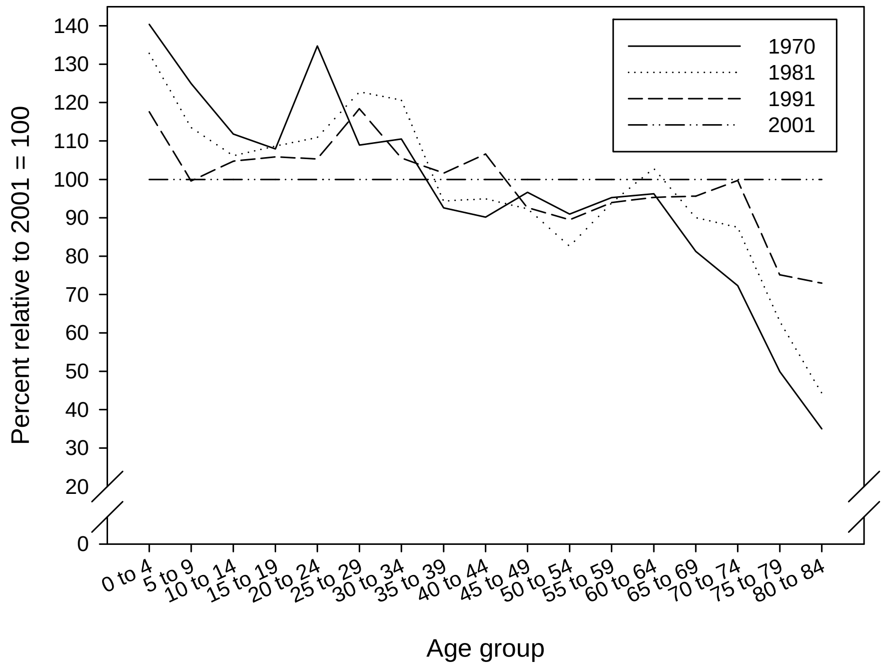



Figure 3.13 Demographic trend 1970-2001 normalised to 2001.

We can now see that proportion of young people has decreased for the past 40 years and the proportion of elderly people (with marked higher cancer incidence risks) has increased.

### 4.2.2 Comparative analysis of cancer incidence rates

As mentioned under the methods section the low cancer numbers in Gibraltar impair the direct very quantitative comparison with other single countries. It is however possible to compare the rates across the European Union and thereby determine if the cancer incidence rates reported in Gibraltar indicate that Gibraltar is a high cancer risk area or not. Herein we compare the Gibraltar mean ± the standard deviation (in the error bar) for the period 1999 (2005) to 2009 with the incidence rate modelled or recorded in the EU-27 countries in 2008. We focus on the primary cancer types where we compare the European age structure standardized rate (EASR) cancer incidence rates.

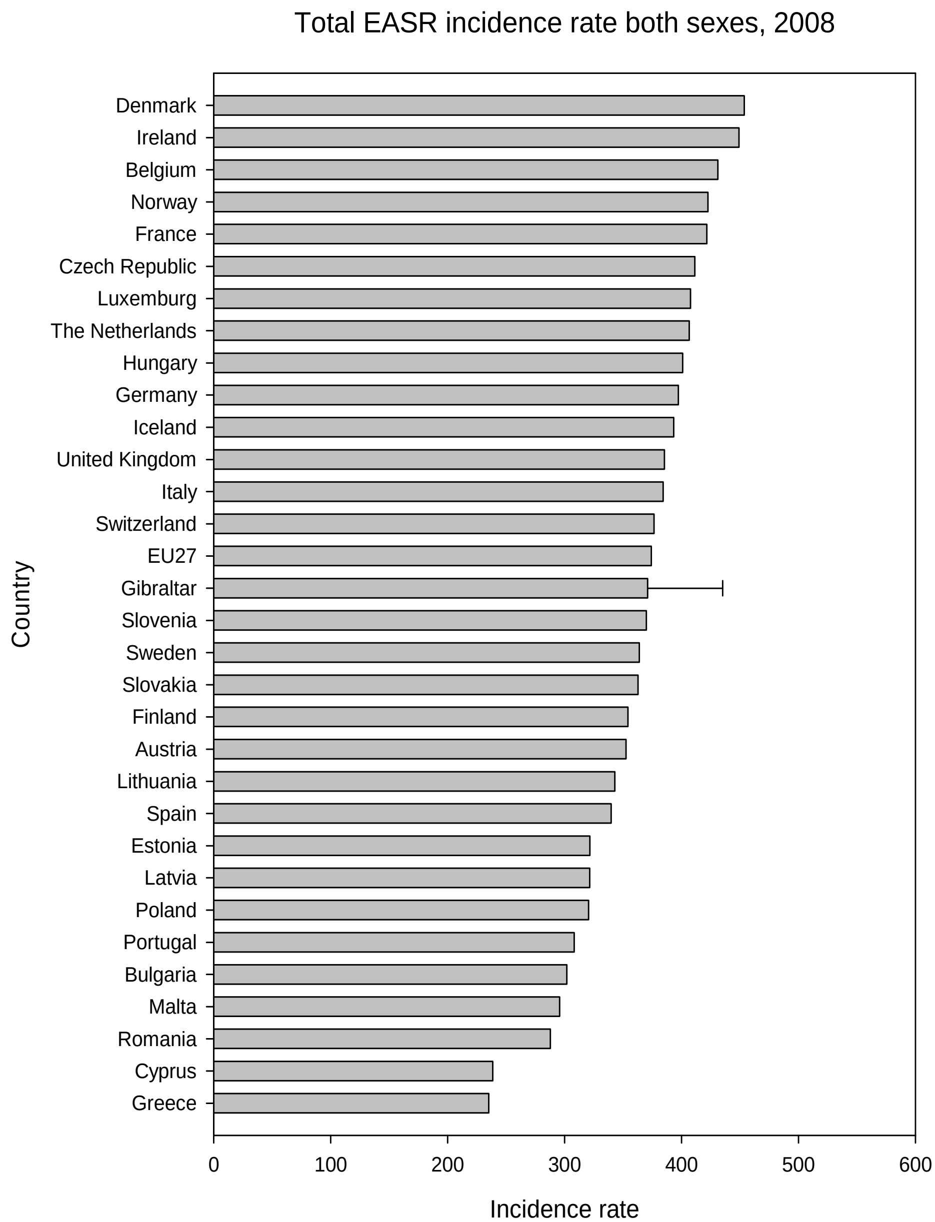



Figure 3.14 Total incidence rate (Gibraltar 2005-2009).

The first endpoint is the total cancers for the entire population. Figure 3.14 shows that Gibraltar on average is within the normal range of the EU, and very close to the EU27 average. In a worst case scenario where all the uncertain files (up to 13% see section 4.2) were positive for cancer, Gibraltar would still be within the normal range of the EU but slightly above the EU27 average.

The overall for females are shown in Figure 3.15 below.

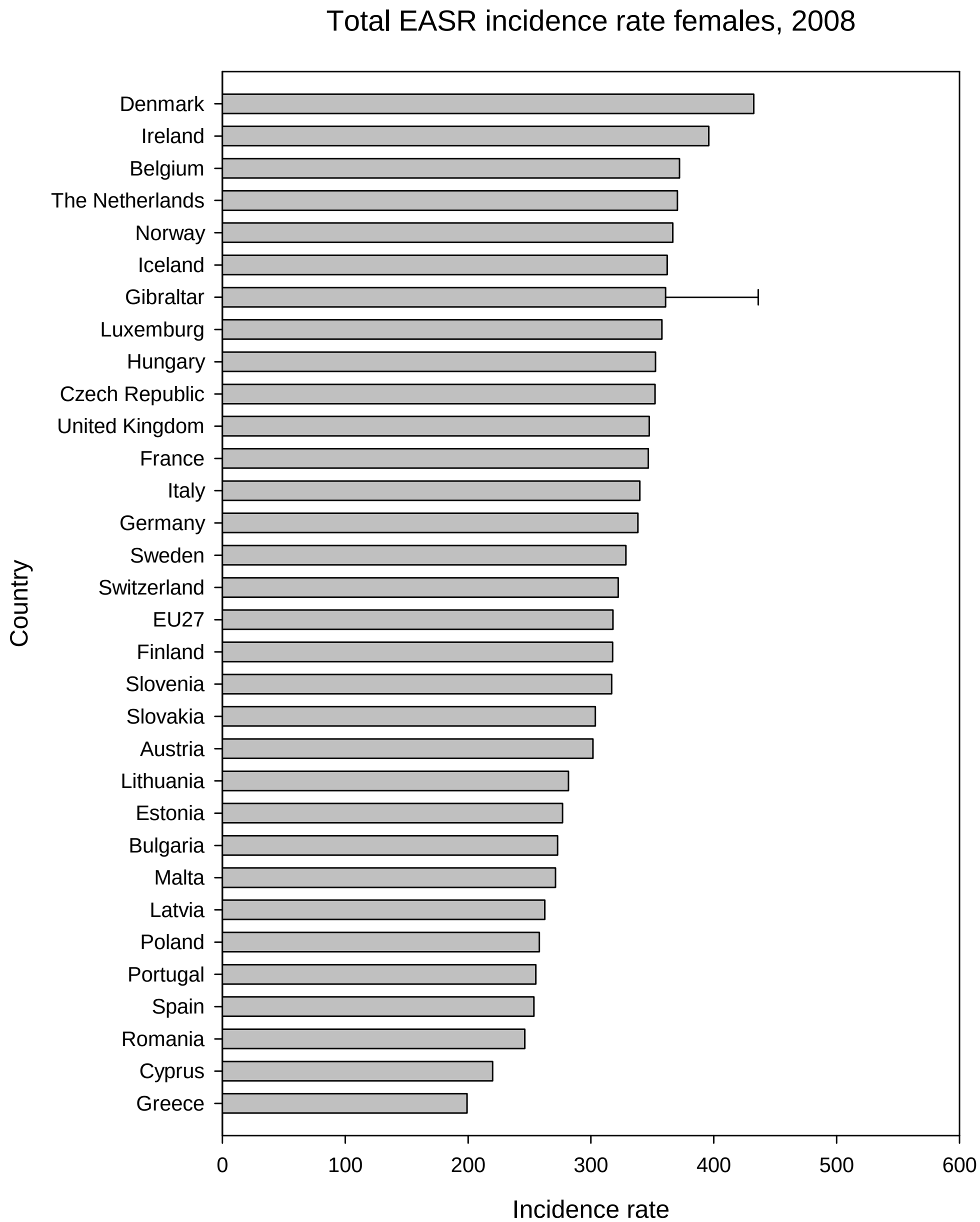



Figure 3.15 Total incidence rate for females (Gibraltar 2005-2009).

The female rate is in the upper 25th centile of the EU countries, but within the normal range of EU countries.

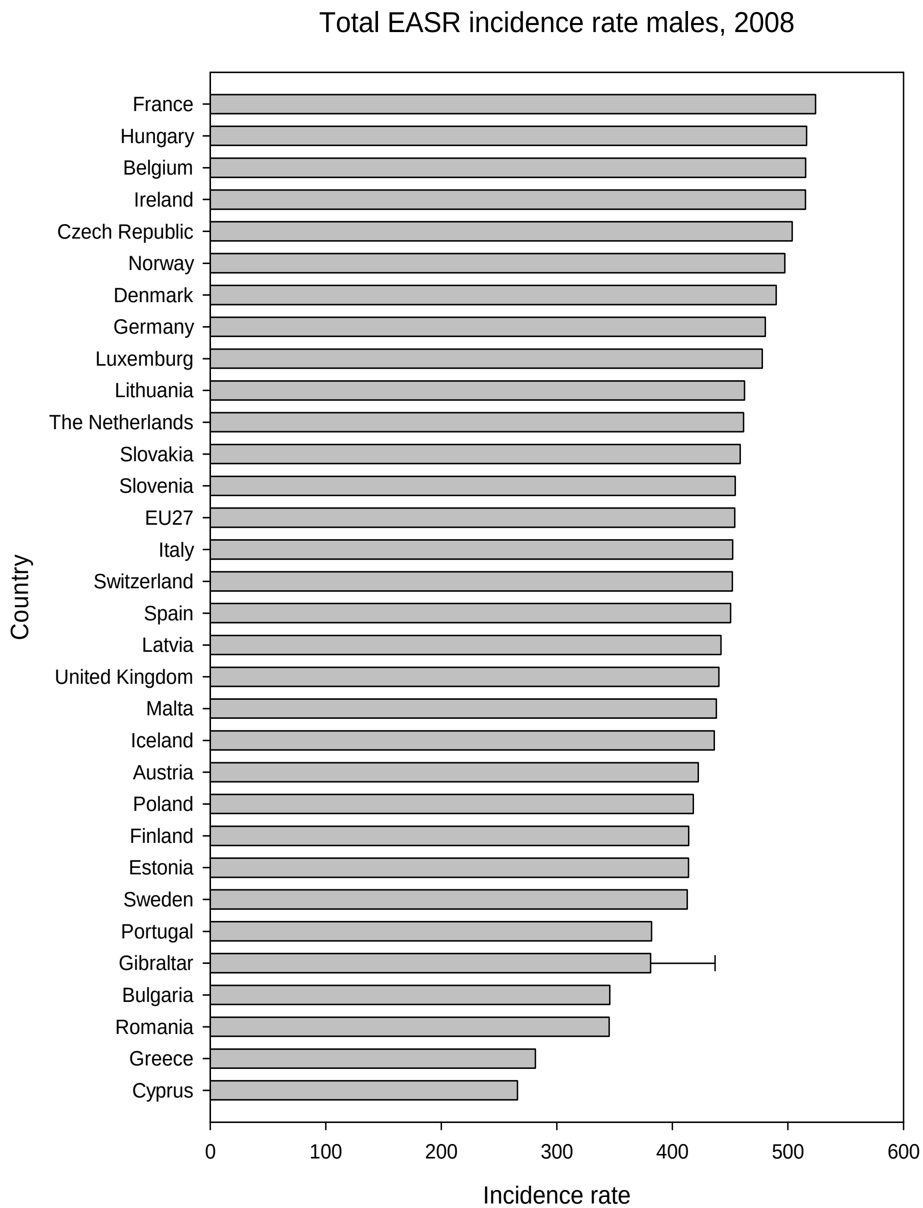



Figure 3.16 Total incidence rate for males (Gibraltar 2005-2009).

The overall rate for males alone is however, in the lower 25th centile as evident from Figure 3.16 above.

Hence, the total cancer incidence rate is at the EU27 average, whereas the rate for females is in the upper 25 % and the rate for males is in the lower 25 % compared to the other 27 EU countries.

There are concerns about lung cancer as a significant cancer type in the EU and the rest of the world.

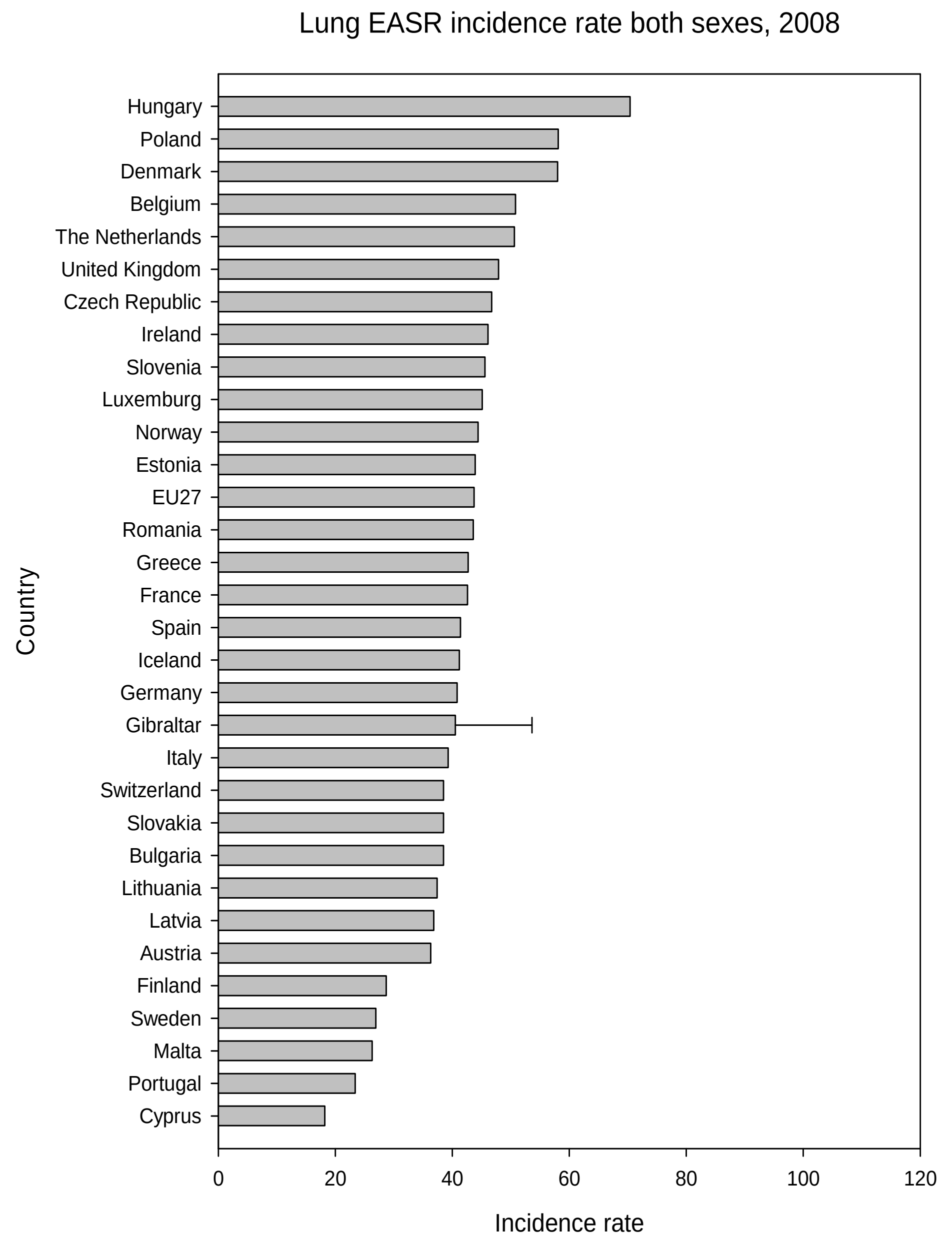



Figure 3.17 Lung cancer incidence rate (Gibraltar 2005-2009).

Gibraltar is in the normal range of the European countries and below the EU27 average for both sexes combined (Figure 3.17).

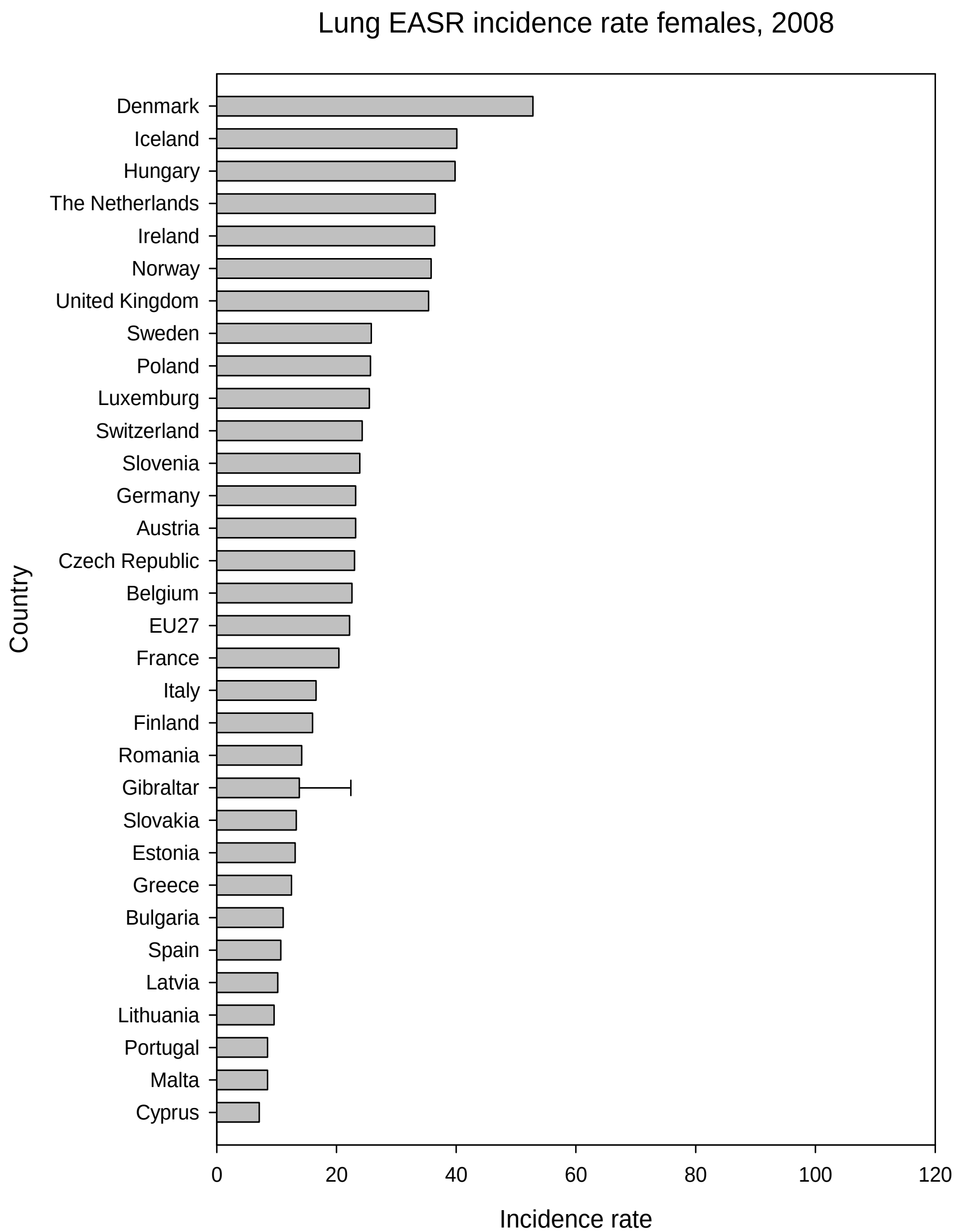



Figure 3.18 Lung cancer incidence rate, females (Gibraltar 2005-2009).

If we focus on the two genders incidence rates in a European context we can see from Figure 3.18 that the female rate is lower than most other EU countries.

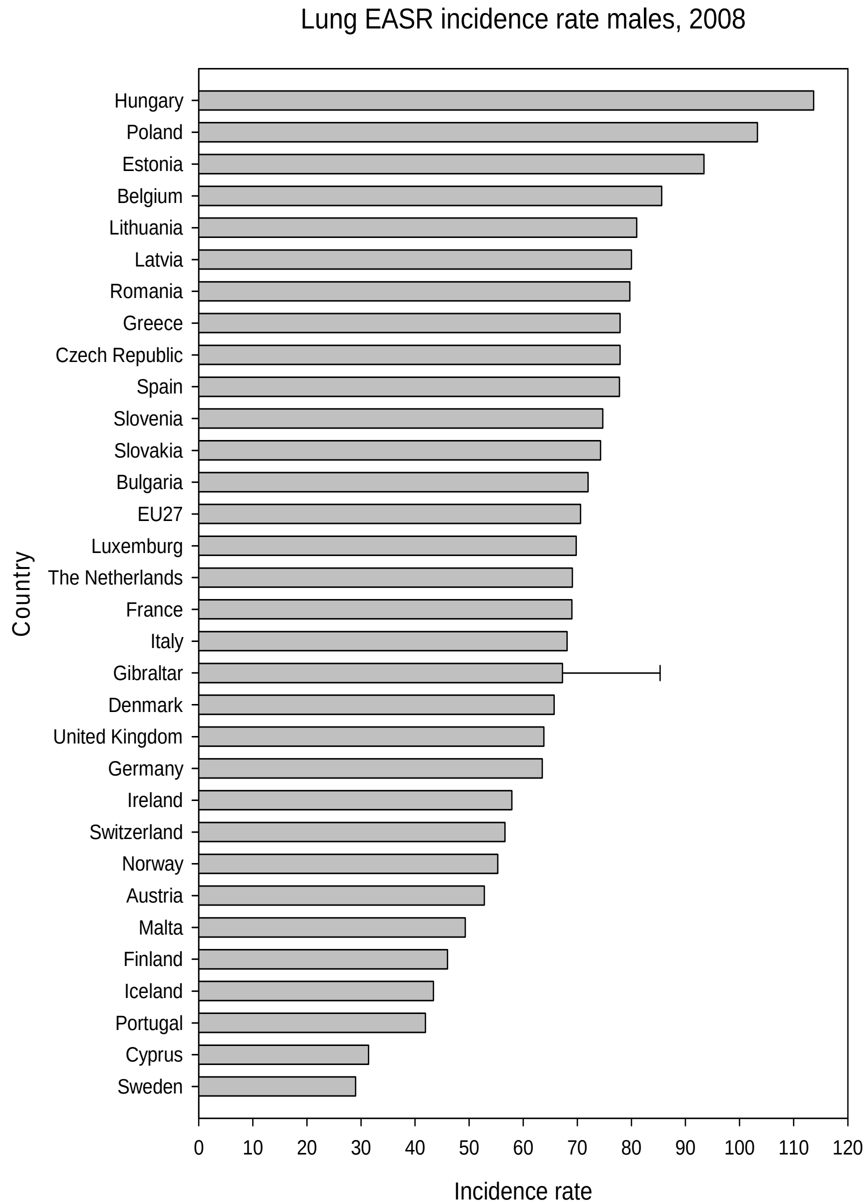



Figure 3.19 Lung cancer incidence rate, males (Gibraltar 2005-2009).

The males rate is lower than most EU countries and below the EU27 average (Figure 3.19).

Another significant cancer type is bladder cancer. The incidence rate is significantly lower than for lung cancer.

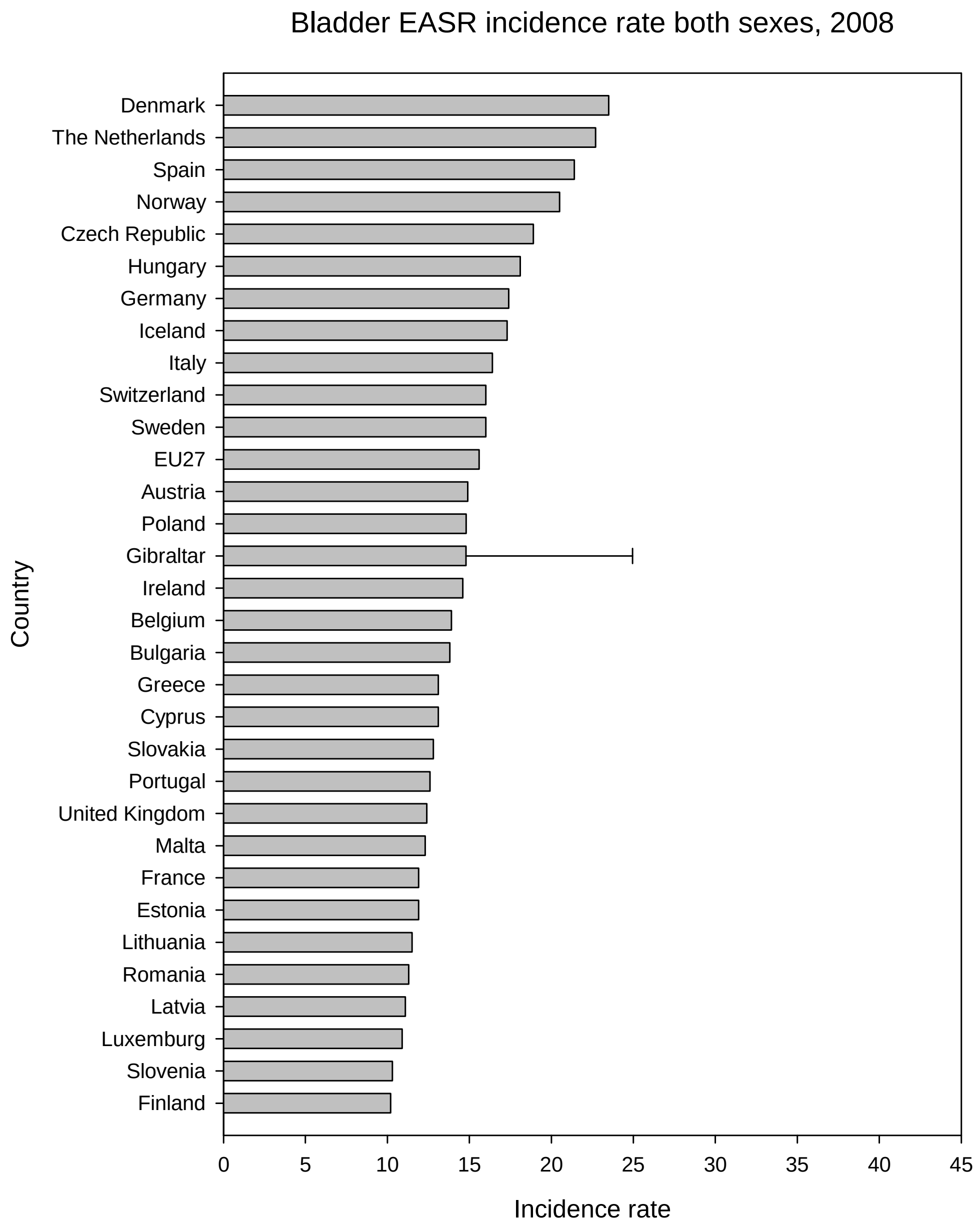



Figure 3.20 Overall bladder cancer incidence rates (Gibraltar 1999-2009).

We can see that the incidence rates are quite variable over the period (1999-2009) in Gibraltar, but well within the normal range in the EU (Figure 3.20).

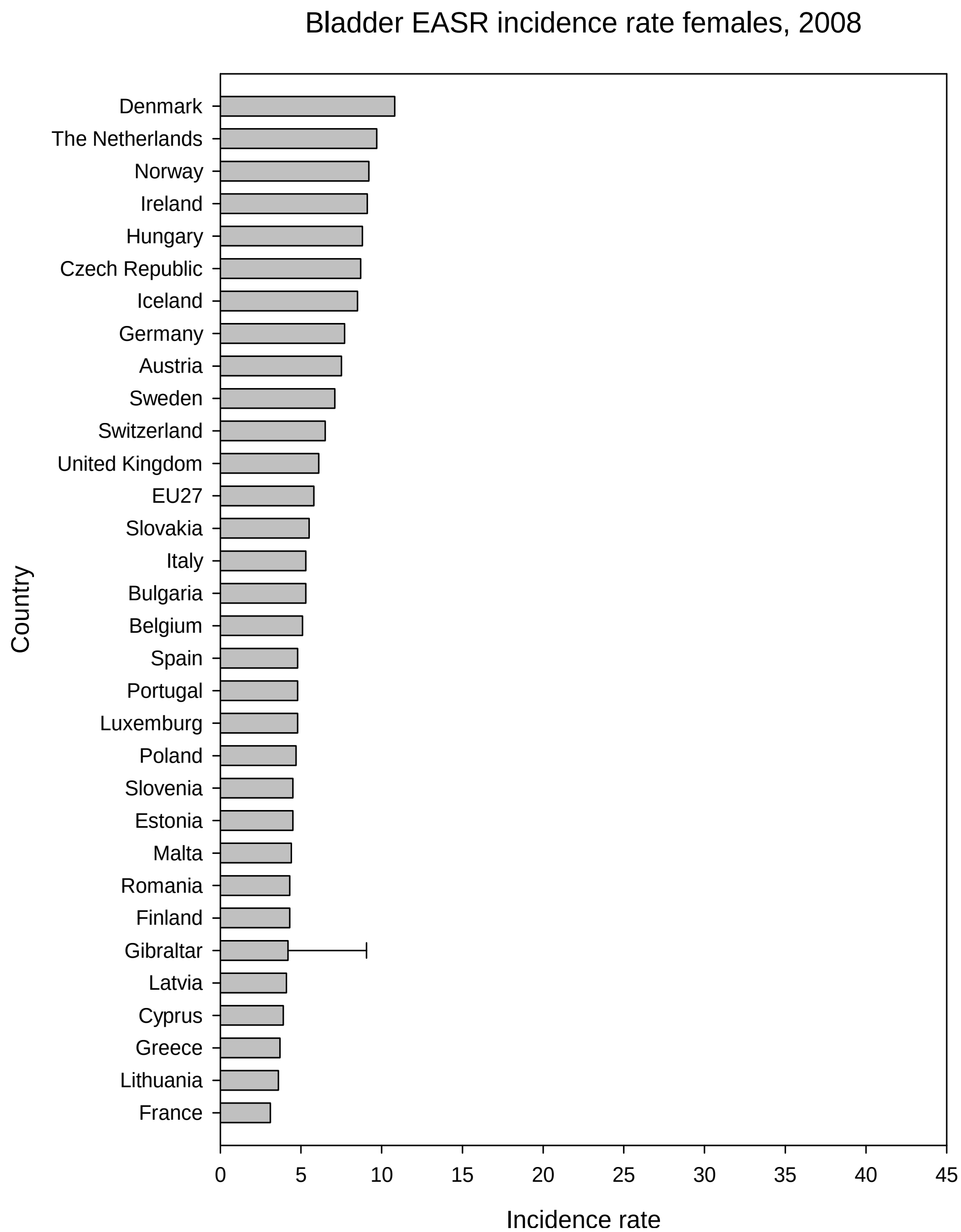



Figure 3.21 Bladder cancer incidence rate, females (Gibraltar 1999-2009).

The incidence rate for females is in the lower centiles among EU countries (sixth lowest).

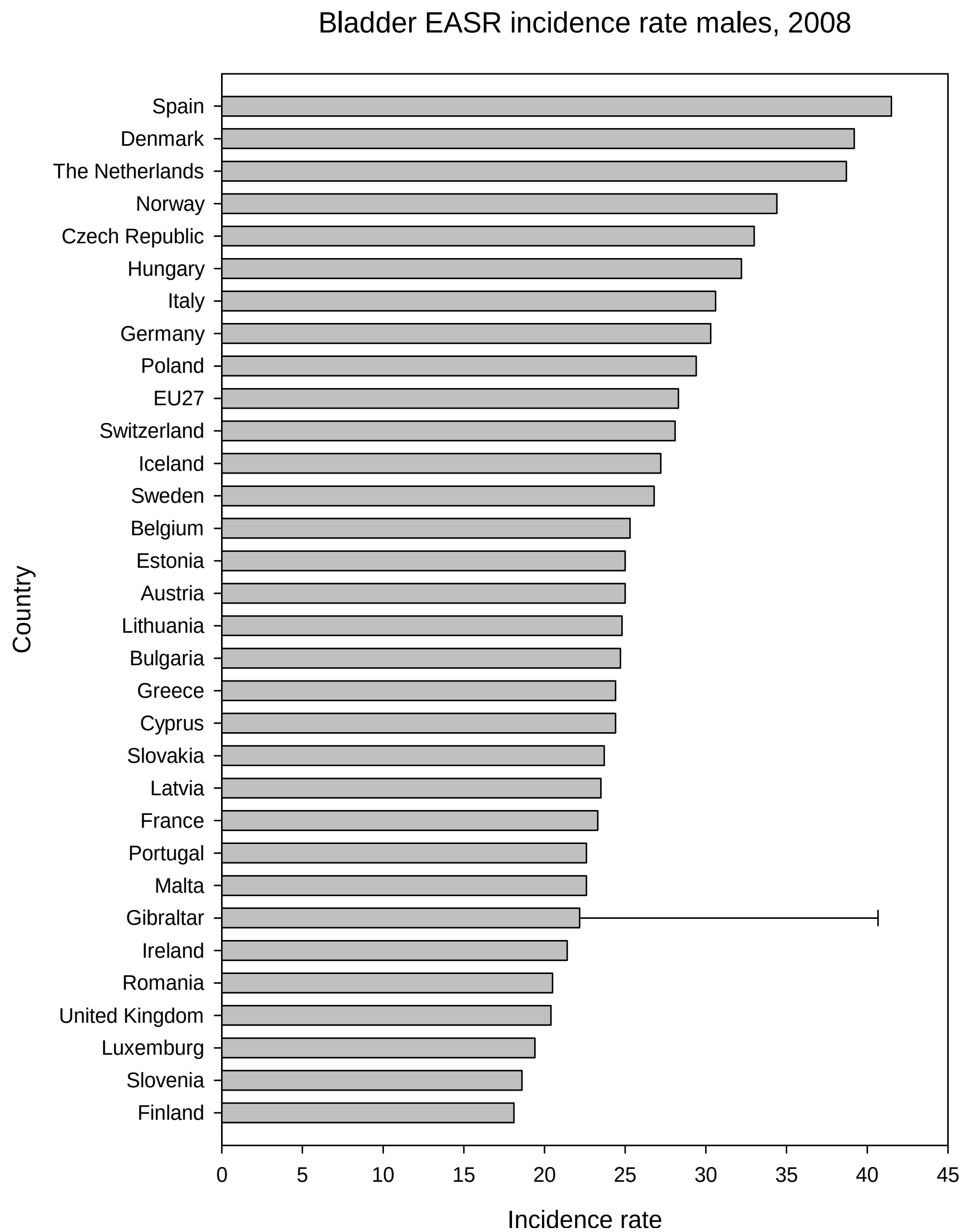



Figure 3.22 Bladder cancer incidence rate, males (Gibraltar 1999-2009).

Males have a marked higher incidence rate than females, however still low compared to other EU countries (seventh lowest).

Colon and rectum cancers also represent a significant portion of the total recorded cancers in the EU.

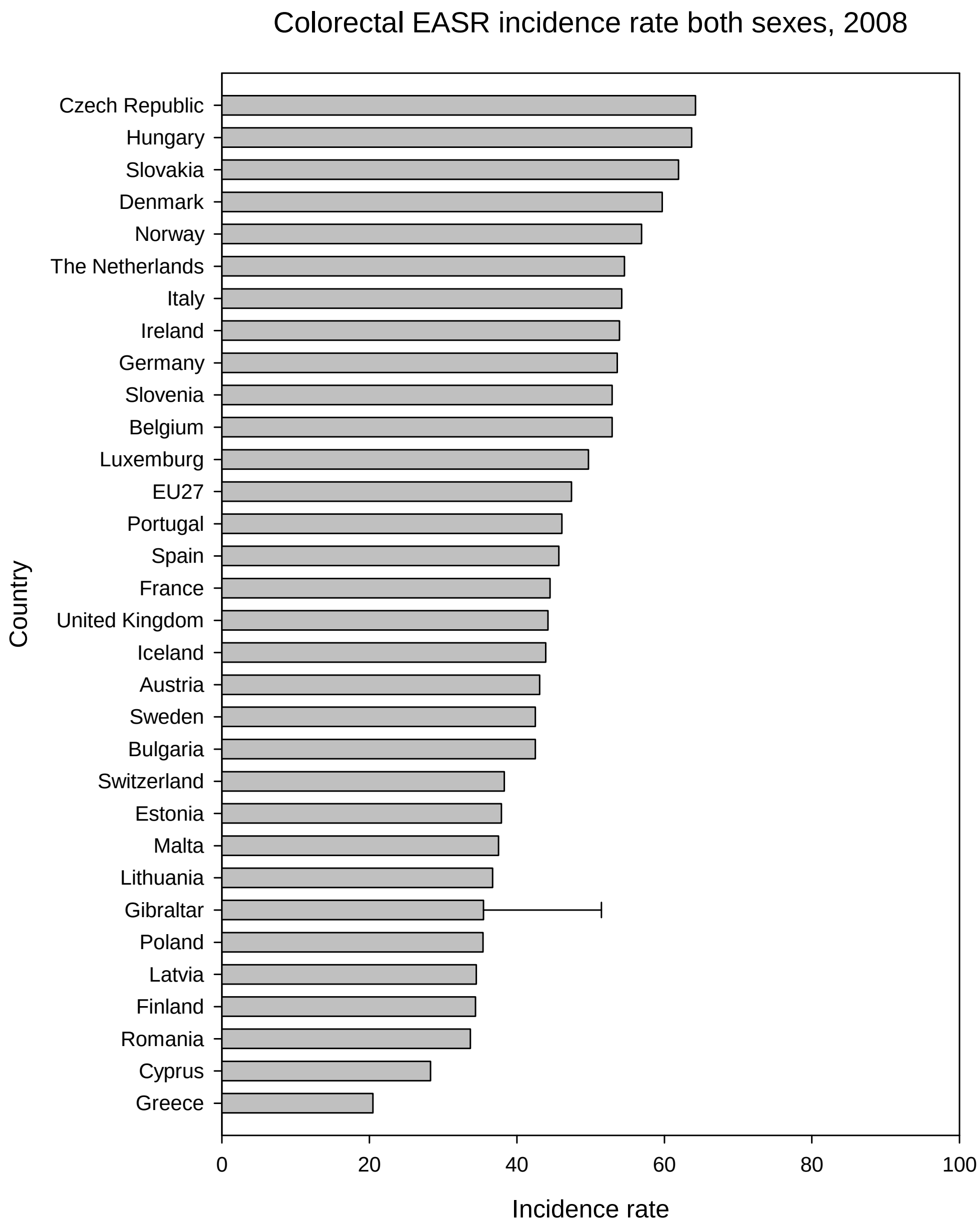



Figure 3.23 Overall colon and rectal cancer incidence rate (Gibraltar 1999-2009).

Gibraltar does not appear to have an elevated incidence rate of this cancer type overall relative to other EU countries (Figure 3.23).

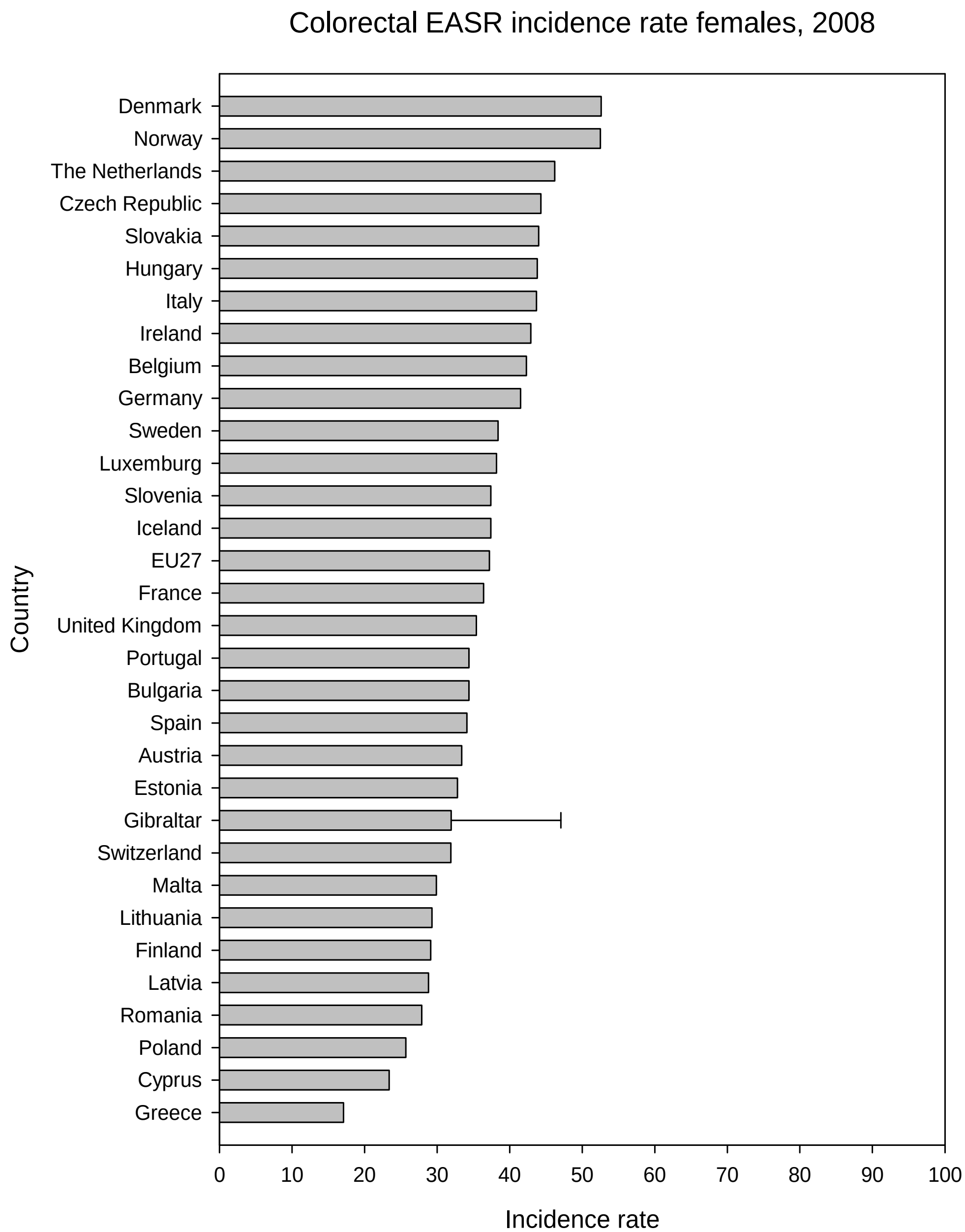



Figure 3.24 Colon and rectal cancer incidence rate, females (Gibraltar 1999-2009).

The incidence rate for females in Gibraltar is also within the normal range of the EU levels (Figure 3.24).

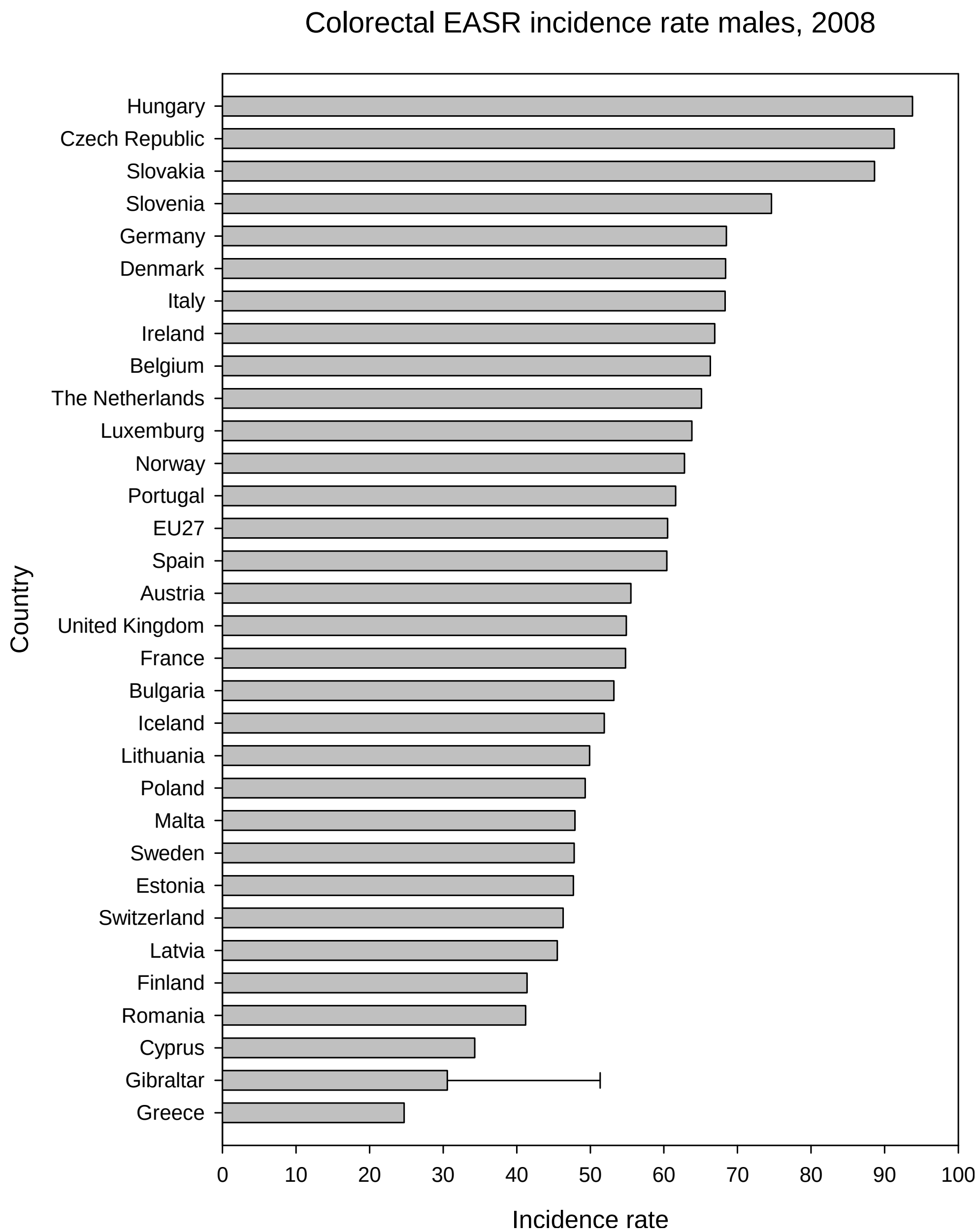



Figure 3.25 Colon and rectal cancer incidence rate, males (Gibraltar 1999-2009).

The rate for males is on average the second lowest among the EU countries (Figure 3.25).

Pancreas cancer is not as frequent as the above cancer types but has a high mortality relative incidence rate in the EU, hence this type of cancer was included in the report.

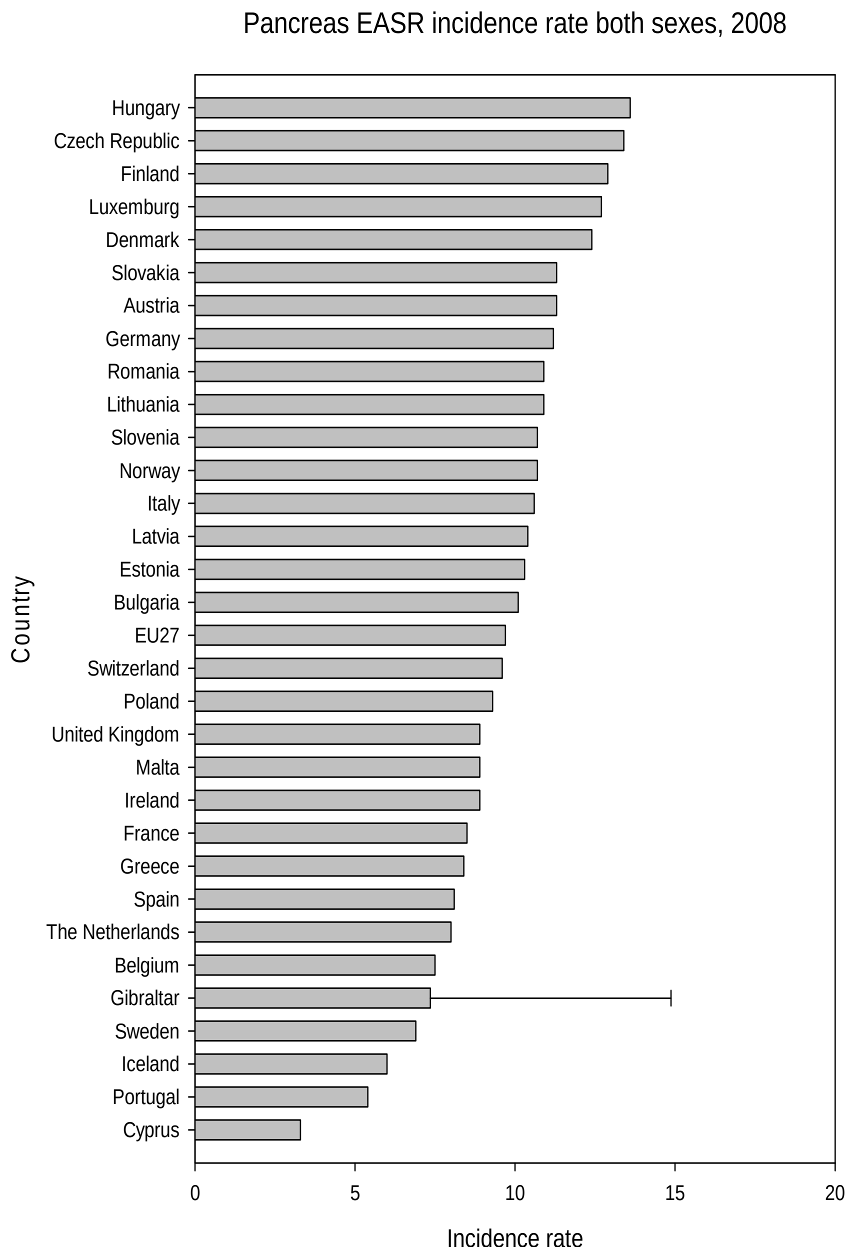



Figure 3.26 Total pancreas cancer incidence rates (Gibraltar 1999-2009).

Overall the Gibraltar average rate is within the normal range of the European countries, but as evident from the error bar it is also somewhat variable, this is primarily due to the small numbers (Figure 3.26).

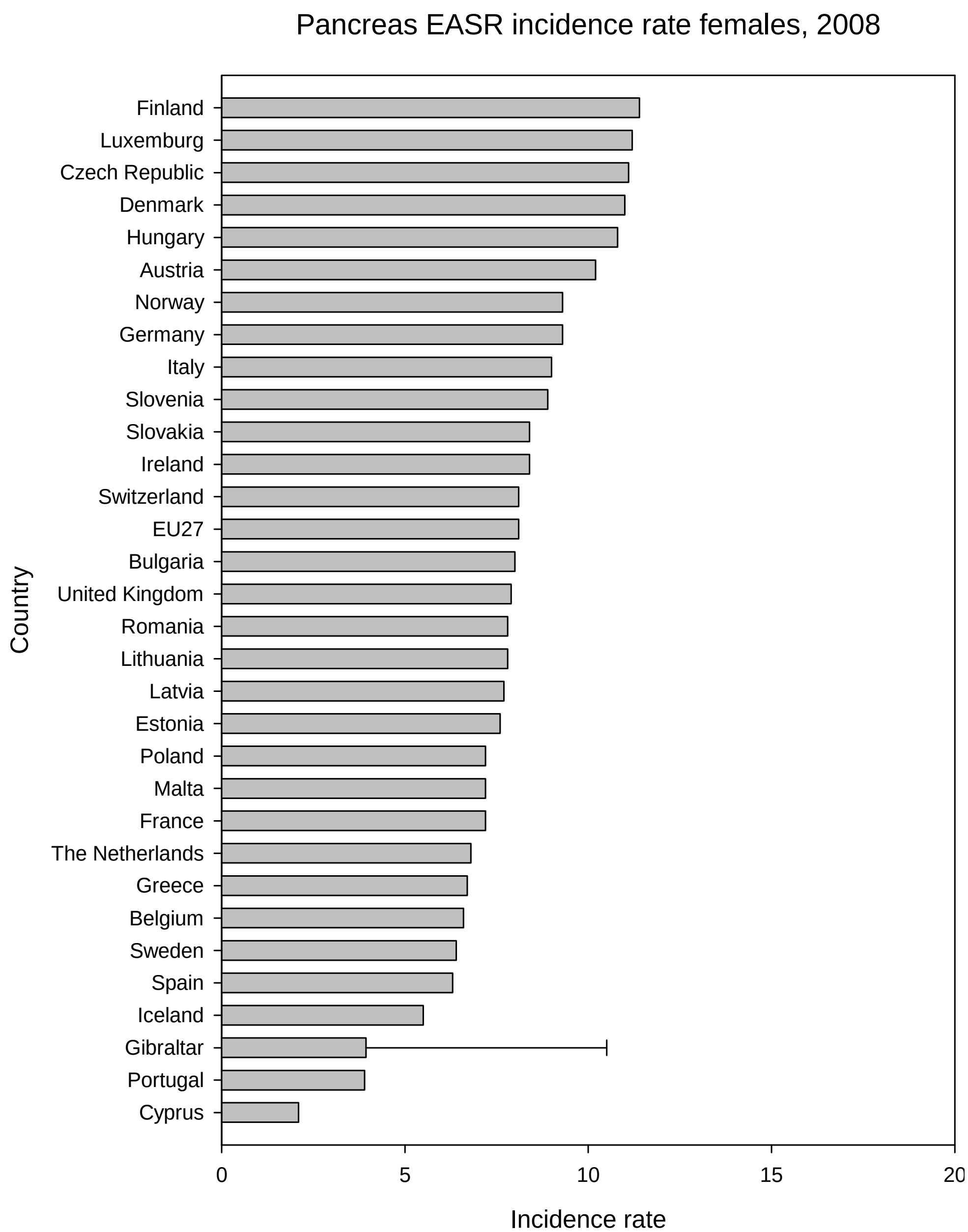



Figure 3.27 Pancreas cancer incidence rates, females (Gibraltar 1999-2009).

The variability is also evident when looking at the rate for females, but still low compared to other EU countries (Figure 3.27).

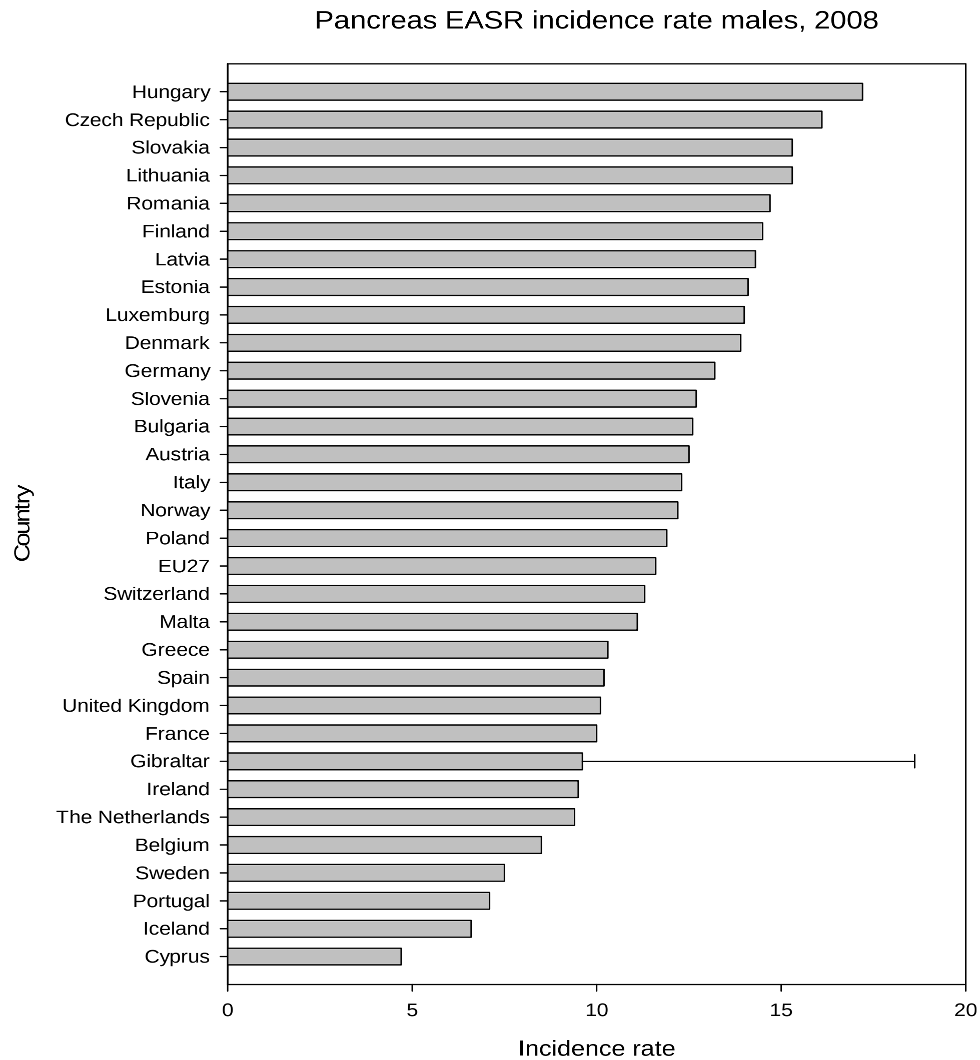



Figure 3.28 Pancreas cancer incidence rates, males (Gibraltar 1999-2009).

The incidence rate of pancreas cancer is highly variable among males over the years, but on average in the lower third among EU countries (Figure 3.28).

We have also included sex specific cancer type (breast, and corpus uteri cancers) and prostate cancer.

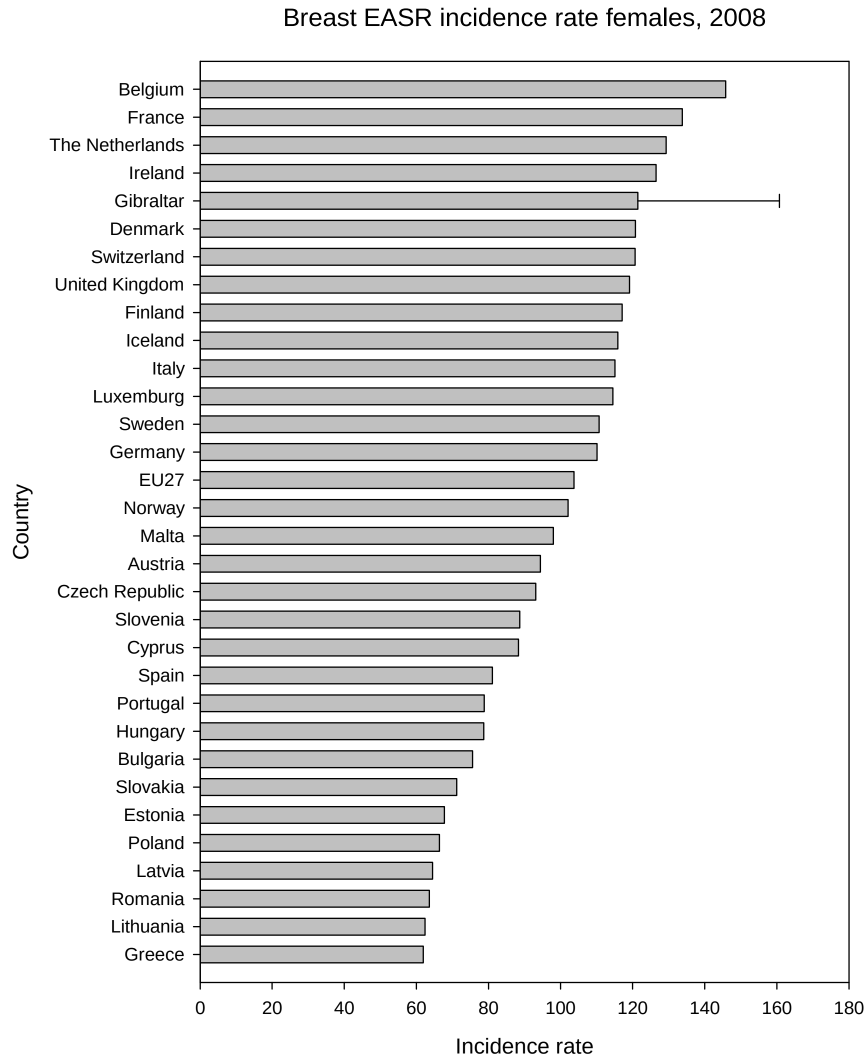



Figure 3.29 Breast cancer incidence rate (Gibraltar 1999-2009).

Breast cancer is the most frequent cancer type among European women. The incidence rate among Gibraltarian women is higher than the EU average and among the highest in the EU (Figure 3.29).

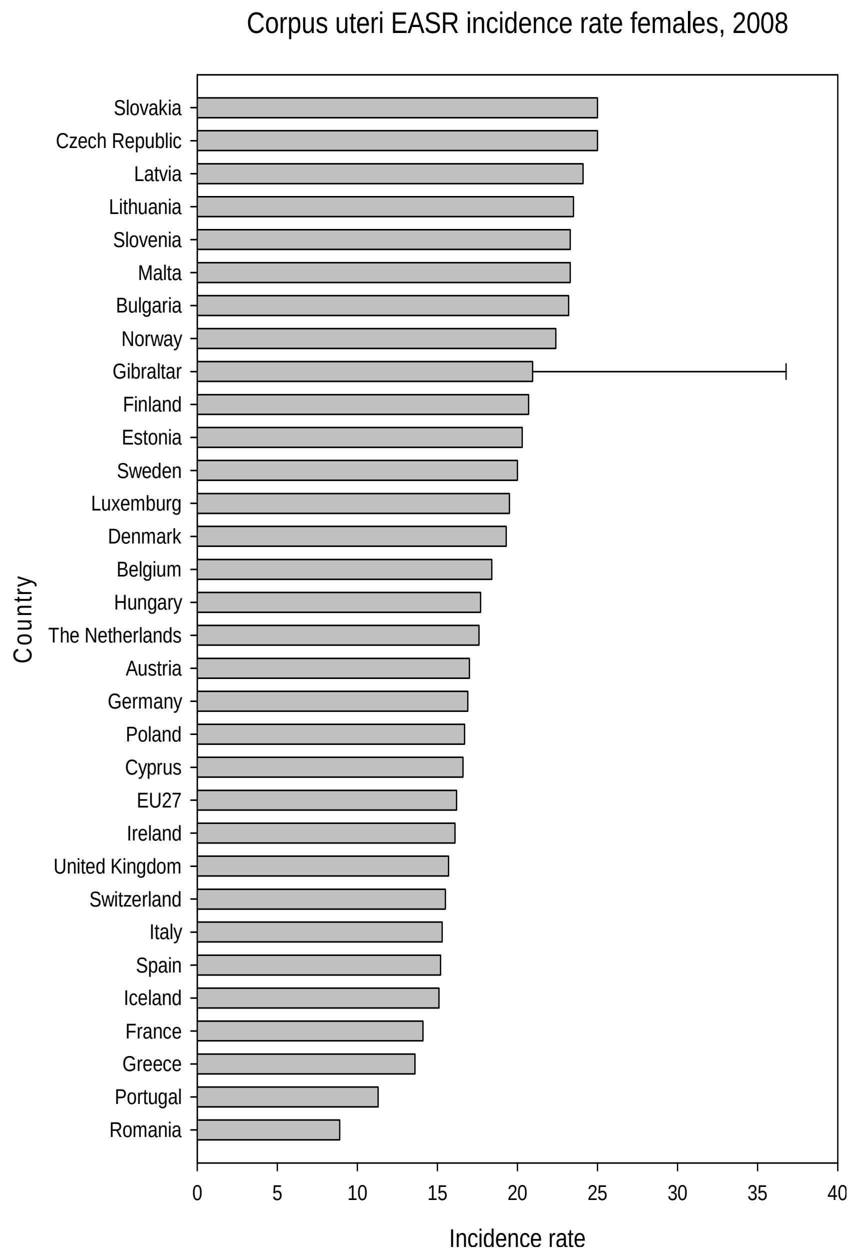



Figure 3.30 Corpus uteri cancer incidence rate (Gibraltar 1999-2009).

Corpus uteri cancer is also of concern. The incidence rate is lower than for breast cancer and also relatively more variable in Gibraltar. Gibraltar is within the normal range of the EU but at the upper end with respect to the incidence rate (Figure 3.30).

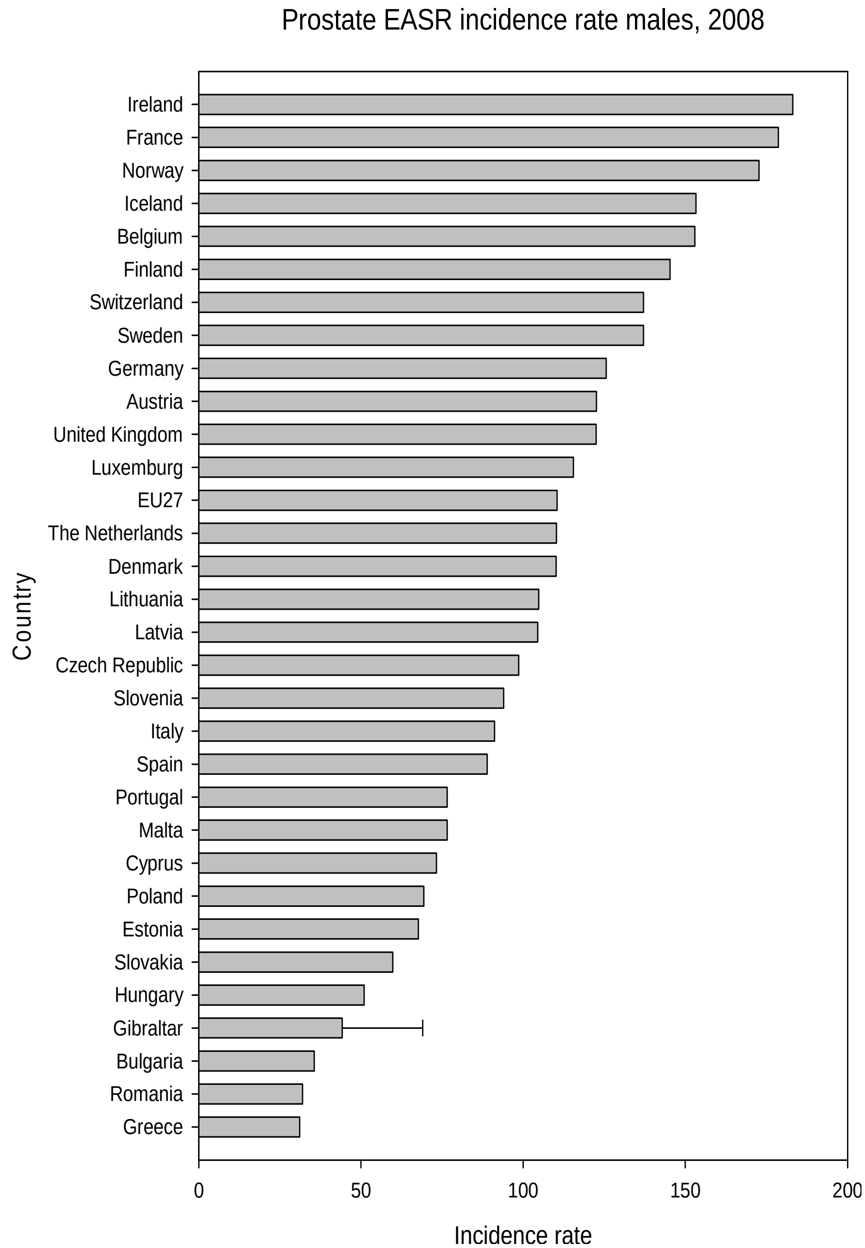



Figure 3.31 Prostate cancer incidence rates (Gibraltar 1999-2009).

The incidence rate for prostate cancer is relatively low for males in Gibraltar compared with other European countries and below the EU27 average (Figure 3.31).

### 4.2.3 Cancers of more specific concern

**Breast cancer**

Breast cancer is globally a cancer type of significant concern as it is one of the most common cancer types, as is also see in Gibraltar. We therefore look further at this disease.

Figure 3.32 below shows trend in registered breast cancers 1999-2009, which seems biphasic. It is quite clear that the period 1999-2005 was more or less consistent with an average of 14.6 cases per year. From 2006-2009 there is an increasing number of diagnosed cases to an average of 24.5 cases per year indicated by the lines in the Figure.

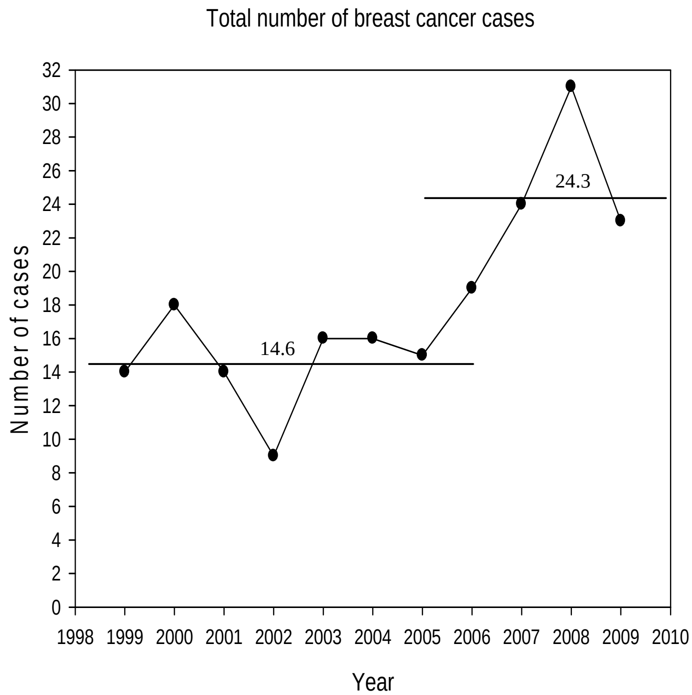



Figure 3.32 Trend of breast cancer cases over time.

The apparent increase should be further investigated and explained, e.g. if the diagnostic methods have become more efficient in the latter part of the period? Comparing to the carcinoma *in situ* of the breast (D05) is not really possible since the case numbers are very small. However, the incidence in the first period is only 0.6 per year but in the second 1.5 per year, suggesting an increase - albeit small.

The age distribution of breast cancer among women is different from the overall distribution of cancers (Figure 3.11). The proportion of breast cancer for the 0-40 year olds only represents some 4 %, whereas the group from 40 to 85+ year olds represents the remaining 96 %, which are then somewhat evenly distributed between the age groups ranging between 7.5 and 12 % for each (Figure 3.33).


Figure 3.33 Age distribution of breast cancer.

**All leukaemia (C91-95)**

Leukaemia is selected to focus on the risks towards children in Gibraltar, and because the monitored 1,3-butadinene in ambient air is within a factor of 15 from the 1:10,000 for primarily leukaemia. Leukaemia accounts for around 1/3 of all childhood cancers, and occurs mainly at 2-3 years of age (Newby and Howard, 2005). There are only 24 registered cases of all types of leukaemia among males and females in Gibraltar, with 12 cases per sex. There is on average 2.2 new cases per year in Gibraltar. The highest number was registered in 2000 with 8 new cases; the other years vary between 0 and 3 cases. There is in other words no significant trend over time. Childhood leukaemia is the most frequent cancer type among children and young persons, which is also evident from the distribution between age groups in Gibraltar (Figure 3.34), which is very different from the general age distribution (Figure 3.11).

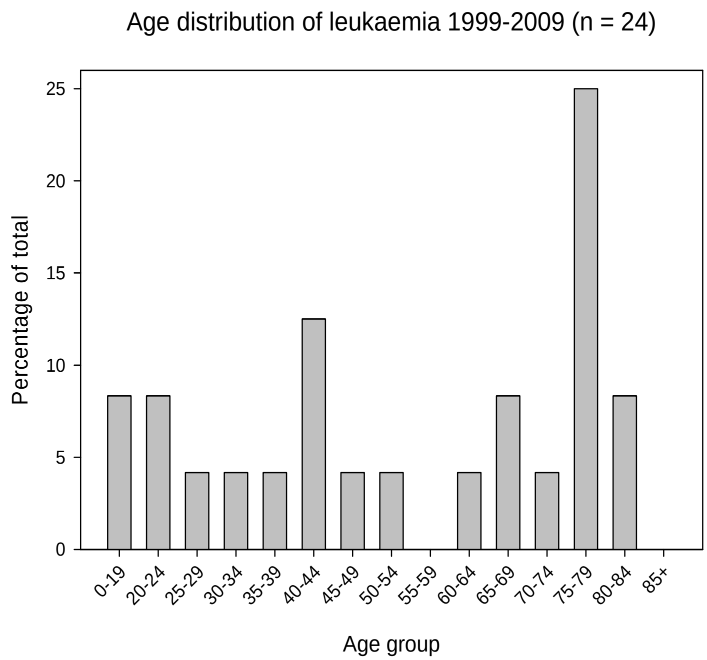



Figure 3.34 Distribution of leukaemia between age groups.

The numbers are very low which impairs a direct comparison elsewhere. With the analysis here we wanted to find out if there was a bias in the data with regards in particular to childhood cancer that would be unusual and of concern, i.e. if the 0-19 year olds represented a disproportional high percentage of the total cancers or if there was a strong bias between boys and girls. None of this is the case, hence we cannot conclude that leukaemia in Gibraltar is significantly different from the expected patterns found elsewhere. Moreover, it is not possible to directly link the 1,3-butadinene exposures to an increased leukaemia incidence rate, but note that 1,3-butadinene potentially contribute to the overall leukaemia risk.

**Thyroid cancer**

Thyroid cancer was chosen because this is very closely related to radiation and not so many other environmental exposures, hence this disease can be used as an indicator for potential high exposure to ionizing radiation in Gibraltar. Low iodine level in diet is also a risk factor and the reason why iodine is added to table salt in many countries across the world (EPH, 2010). There are registered a total of seven cases of thyroid cancer registered from 1999-2009 for people aged 30-80 years. The seven cases were found in 2000, 2002, 2004 and 2005, with four male and three female cases. These low numbers does not support the theory that there is an elevated cancer concern due to radiation and thyroid cancer, nor that the ionizing radiation is expected to be critical in Gibraltar.

# 5 DPSEEA WoE analysis

The point of departure for the weight-of-evidence analysis of the cancer epidemiology in Gibraltar is on the cancers of concern and secondly the exposures of concern. In Chapter 3 we focussed on the most prevalent cancer types that allowed international comparison with the least bias in variability due to small numbers. Among these the cancer type that caused the greatest concern was female breast cancer with a relatively high incidence rate compared to the other EU countries and a high percentage of the total cancers among women from Gibraltar (38 %). All the other cancer types are within the normal range of the rest of the European Union or have so low numbers that a comparable incidence rate is not computable.

In addition we included the following cancers of concern:

- Leukaemia (concern of specific risks towards children and young people that may be masked in the totals of the other diseases and age totals). Moreover, leukaemia is associated with some of the environmental exposures we have analysed.
- Thyroid cancer, as this cancer is very specific towards radiation, hence the radiation risk and thyroid cancer risk should, all other being equal, correlate.
- Moreover, we know that air pollution is a significant contributor to the total cancer risk burden and specifically to lung cancer, hence lung cancer and air pollution is of a specific concern in this and most other studies. Lung cancer is however confounded by the significant contribution from smoking, which is out side the scope of this analysis.

Herein we will analyse breast cancer, leukaemia, and lung cancer in relation to the measured and modelled exposures from the environmental compartments.

The factsheets on the different environmental compartments all show that individual stressors and contaminants are below the threshold of concern, with the exception of three ambient air pollutants.

## 5.1 Air pollutants – co-carcinogens

Co-carcinogens are compounds or particles that by themselves are not known carcinogens but may potentially enhance the carcinogenicity of other carcinogens. The co-carcinogen can contribute to an enhanced transport of for example PAH sorbed to the co-carcinogenic molecules or particles, resulting in the deposition of PAH in the pulmonary system (Newby and Howard, 2005). We have listed the co-carcinogens that exceed or are close to the guideline values reported in the EU Air Quality Guidelines second edition (2010) either via the measured exposure concentrations or the modelled ditto, see Table 3.11 (page 47).

- $SO_2/SO_x$ (IARC group 3 – limited and/or inadequate evidence of carcinogenicity – not classifiable as to its carcinogenicity to humans).
- $NO_2/NO_x$ (no IARC classification).
- Ozone (no IARC classification).
- Trichloromethane (no IARC classification).
- Ethylbenzene (no IARC classification).
- Chlorine and its inorganic products (no IARC classification).
- $PM_{2.5}$ and $PM_{10}$ (no IARC classification).

As mentioned above, by themselves these compounds do not represent a cancer risk, but they can elevate the cancer risk of other carcinogens, however, the exact additive effect they exert in relation to the carcinogenicity of other carcinogens, and thus the exact magnitude and role they play in relation to the overall cancer risk is site specific and largely unknown. They are included here as a precaution and only as co-carcinogens to demonstrate that the aspect of mixture is important to consider if not quantitatively then qualitatively. If the compounds comply with the Gibraltar and international air quality criteria we conclude that they are not relevant as contributors to an elevated cancer risk in Gibraltar.

Based on the recent Annual Reports from the Department of the Environment in Gibraltar and the air quality monitoring program in Gibraltar we can conclude that all the co-carcinogens comply with the air quality criteria, with a few exceptions detailed below.

The annual mean $NO_2$ concentration has, in the recent years, been slightly higher (approx. 10 %) than the Gibraltar air quality objective of 40 µg $m^{-3}$ (Figure 4.1). The results from a dispersion modelling study by AEA have concluded that the diesel power station emissions accounted for a significant proportion of the measured $NO_2$ concentrations.

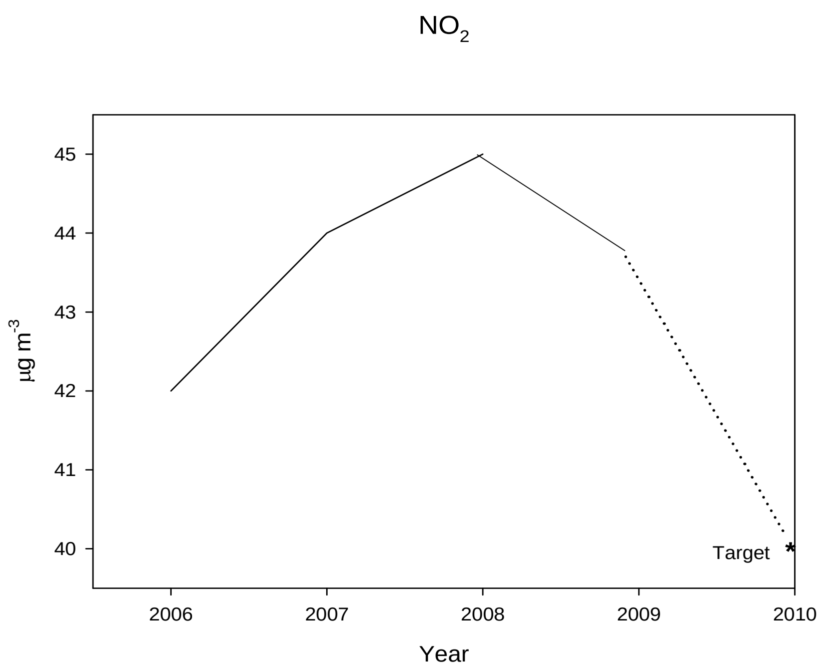



Figure 4.1 Annual average of $NO_2$ in air. Dotted line is projected to reach air quality objective.

$PM_{10}$s are a specific concern as they are probably the most effective co-carcinogen relative to their ability to absorb carcinogens (e.g. PAH) and transport in the lungs. The number of days where the air quality objective for $PM_{10}$ was exceeded for the period 2006-2008 during the course of each year is shown below (Figure 4.2).

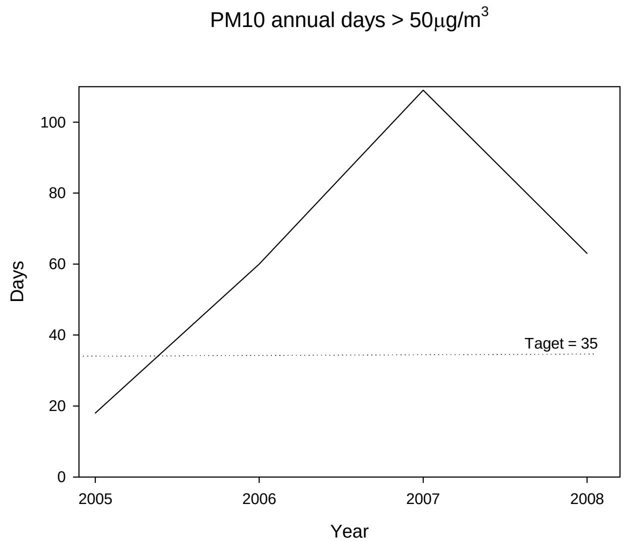



Figure 4.2 Number of days with $PM_{10}$ > 50 µg $m^{-3}$.

## 5.2 Air pollutants – carcinogens

Table 4.1 includes the monitored carcinogenic air pollutants in Gibraltar, unless otherwise stated. The list is comprised of compounds where the margin of exposure (MoE) (acceptable risk level (1:10,000 cancer risk)/exposure level) is less than 100 for the year 2008. The acceptable risk level, here 1 in 10,000, is the starting point for most acceptable cancer risk levels and could be multiplied by a factor of 10-100 up to 1 in 1 million. Depending upon the risk acceptability, which is a risk management decision.

Table 4.1 Exposure is based on monitored annual mean air concentrations for 2008, unless otherwise stated.

| | Compound | Gib Exp *µg/m³* | EU Exp. *µg/m³* | EU/Gib *exposure ratio* | 1:10,000 risk *µg/m³* | IARC *grp* | Cancer *type* | MoE *ratio* |
|---|---|---|---|---|---|---|---|---|
| Heavy metals | Chromium | 0.007[2)] | 0.005-0.2 | 0.7-30 | 0.0025 | 1 | Lung | 0.36 |
| | Nickel | 0.02[1)] | 0.001-0.18 | 0.05-9 | 0.25 | 1 | Lung | 7.3 |
| | Arsenic | 0.00128[1)] | 0.03-1 | 20-800 | 0.02 | 1 | Lung | 16 |
| | Lead | 0.011[1)] | 0.15-0.5 | 10-50 | NA | 2A-3 | Stomach (lung, kidney, brain, bladder) | NA |
| VOCs | PAH (total) | 0.0052[4)] | 0.001-0.01 | 0.2-2 | 0.0012 | 1 | Lung (bladder; colon) | 0.23 |
| | Trichloroethylene | 37[3)] | 10 | 0.3 | 230 | 2A | (Liver kidney; NHL) | 6.2 |
| | Tetrachloroethylene | 31[3)] | NA | NA | 250[5)] | 2A | (Leukaemia; skin; colon) | 31 |
| | Benzene | 2.2[1)] | 5-20 | 2-9 | 13 | 1 | Leukaemia | 5.9 |
| | 1,3-butadiene | 0.2[1)] | 2-20 | 10-100 | 3 | 2A | Leukaemia | 15 |

IARC grp 1 = known human carcinogen.

IARC grp. 2A = Limited evidence in humans for the carcinogenicity, but sufficient evidence in experimental animals for the carcinogenicity - probably carcinogenic to humans.

1) Monitored concentration.

2) Modelled concentration; no monitored concentration.

3) Modelled concentration; no monitored concentration; 2005 municipalities only.

4) Total PAH is derived from monitored B(a)P concentration.

5) Reference concentration (RfC).

NA: not applicable.

The primary exposure route is pulmonary for these air pollutants, and it is thus not surprising that the primary cancer type is lung cancer for these pollutants, with benzene, 1,3-butadiene with regards to leukaemia as the exceptions. Trichloroethylene and tetrachloroethylene are probable human carcinogens, but the epidemiological and cancer pathological data is limited making it difficult to determine which cancer type they are mainly associated with, but the evidence suggests liver and leukaemia, respectively.

The levels of lung cancer in Gibraltar are within the lower centiles of what is found in the EU (Figure 3.17). Leukaemia and liver cancer are not directly comparable to the rest of EU due to the low number of cases in Gibraltar, however, the age distribution of leukaemia in Gibraltar suggest that this type of cancer is not a site specific risk in Gibraltar (Figure 3.34). There is a reported total of 16 cases of liver cancer for the 1999-2009 period (9 female and 7 male in the 55+ age group) with 1-2 cases each year, which is the 14th lowest number of cases among the 33 reported cancer types – it is highly unlikely that liver cancer in Gibraltar based on the data represent an elevated site specific risk.

Ranking of the heavy metals with respect to most likely to potentially elevate cancer risk, we can see that lead is the least carcinogenic of the four and the measured concentration is below the concentrations in other EU cities. For chromium we only have recognized modelled values, which lie in the low range compared to other EU cities, however with the second lowest MoE. The modelled values may be overly conservative due to the modelling assumptions but at the same time potentially important sources are not included. This leaves us with nickel and arsenic where we have reliable measured data. Arsenic is measured at concentrations below the lower level of what is measured in other EU cities, whereas nickel is measured within the normal range of the levels found in EU cities. They have comparable margin of exposures but arsenic is more carcinogenic. Hence, the conclusion regarding the heavy metals is that lead is of minor cancer concern; chromium is of potential concern but lack measured data; nickel and arsenic are of similar concern specifically with regards to lung cancer since they have similar MoEs.

A similar analysis of the volatile organic compounds (VOCs) reveals that there is a lack of measured trichloroethylene and tetrachloroethylene exposure values. The conservative modelled value of trichloroethylene is higher than that found in other EU cities. However, their carcinogenicity is limited and they are the least carcinogenic of the VOCs, hence they are of least concern. 1.3-butadiene is measured and is found below the lower levels found in other EU cities, moreover, the compound is also of relative low concern due to relatively lower carcinogenicity. This leaves PAH and benzene. PAH is clearly of greater concern than benzene, it is more carcinogenic, has a lower MoE, moreover, the concentration of PAH is in the range found in other EU cities, whereas benzene in Gibraltar air is below the levels found in other EU cities.

In conclusion, the relevant carcinogens in air are nickel, arsenic and PAH, noting that chromium could be considered if the modelled concentrations are verified by measured concentrations. These four all cause lung cancer and are potentially amplified by $NO_2$, however, as documented previously the lung cancer incidence rates in Gibraltar are low compared with the rest of the EU suggesting that even though these four compounds theoretically pose a lung cancer risk this is not reflected in an elevation of the incidences in Gibraltar.

The trend with regards to the measured annual mean values for the past 4-5 years indicate arsenic and PAH (here as B(a)P) are significantly below the air quality guideline values, whereas nickel is closer to the guideline value (Figure 5.1a-c).

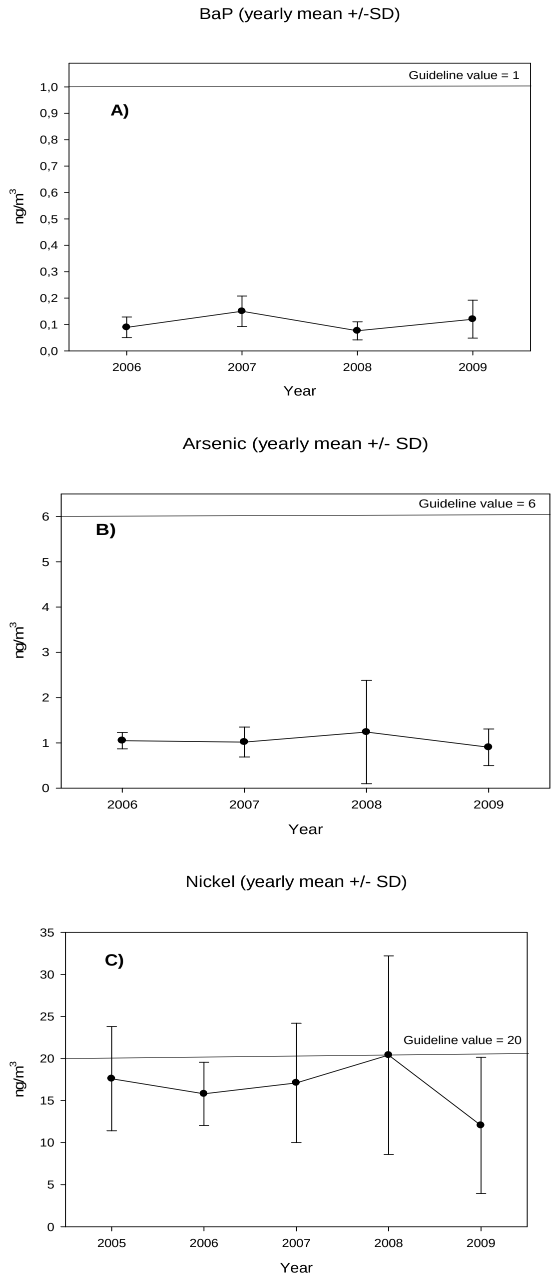



Figure 5.1a-c Measured annual mean ambient air concentrations of priority carcinogens.

It is clear from the Figure 5.1a-c above that nickel is both more variable and closer to the guideline value than the two other compounds.

The model results reveal that the contribution from industrial sources exceeds that from the diffuse sources from adjacent municipalities. There is a decrease in annual mean air concentrations from industrial emissions between years 2005 and 2008. This is reflected in the time-trends in emission rates from industries, except for nickel, as shown in Figure 3.2 (page 34-37).

The contributions of these compounds to the ambient air from industrial sources show that the refinery CEPSA has the relatively highest emission rates and contribution to the Gibraltar air concentration for all four pollutants. CEPSA, Petresa and Lubricantes del Sur have relatively high emission rates for nickel. Interquisa has relatively high emission rates for PAHs with a notable decrease in PAH emissions from 2006 to 2007, whereas the contribution from CEPSA is more constant. For arsenic only CEPSA shows a continuous trend and contributes to the 2008 air concentration together with Edar de la linea de la concepcion. Central termica Los Barrios, CEPSA, Generacion electrica peninsular and Cogeneracion de Interquisa are the most significant contributors of $NO_2/NOx$. CEPSA and Acerinox have the relatively highest emission rate for chromium and contribute the most to the air concentration. Carcinogenic pollutants contributions from CEPSA flaring in Spain, ship traffic in the Bay and Strait, local road traffic and local diesel generators are currently un-quantified. The relative industrial contributions for the primary carcinogens to Rosia Road are depicted in Figure 5.2 based on modeling of the emissions, with CEPSA as the primary contributor, due to its activities and relative size.

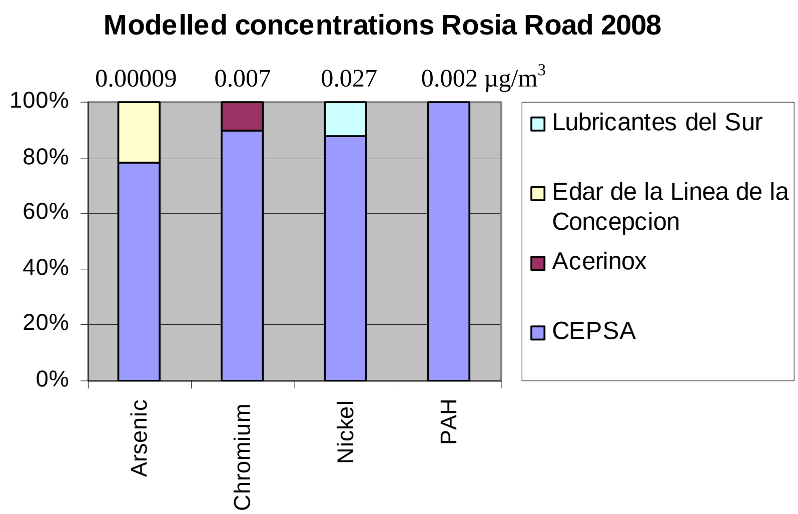



Figure 5.2 OML-Multi modelled air concentrations at Rosia Road for four priority carcinogens based on 2008 industrial emission rates from E-PRTR.

# 6 Conclusions

These are the questions we were asked to address:

1. *To establish whether there actually exists a greater than expected incidence of cancer in Gibraltar*.

**Re 1**) The total cancer incidence rate in Gibraltar is within the normal ranges of other European countries (Figure 3.14– 3.16, page 60-62). Hence, the incidence of cancer is not greater than expected.

The incidence rate is highly dependent upon the age structure of the population. The changes towards less young and older persons in Gibraltar will over time contribute significantly to the increasing cancer incidence rate. This does however not explain the trend over the past 5 years, with increases and decreases of up to 30 % in total cancer incidence rates between years (Figure 3.5, page 50). The reason behind these fluctuations is among other things the relatively small numbers and population, by the law of large numbers. Even if the 13% of uncertain files as explained in paragraph 4.2 on page 48 were all cancer cases with the same distribution among types as the rest of cancer in the registry this would not change the overall conclusions that Gibraltar is within the normal range of cancer incidents rates in the EU as evident from the figures 3.14 to 3.31.

2. *To establish whether Gibraltar is a high-risk community for cancer, due to its location within the vicinity of potential sources of environmental exposure or health hazards, which potentially result in unacceptable levels of exposure to contaminants or pollutants*.

**Re 2**) As shown under 1) Gibraltar is not a high-risk community for cancer in general as the incidence rates are within the normal ranges of the EU. Moreover, the exposures in Gibraltar are within the normal ranges of EU cities (Table. 4.1, page 84).

Gibraltar is however, an urban environment with emissions and therefore exposures to contaminants from anthropogenic activities, hereunder industries and transport. For the most part these exposures comply with Gibraltar and international guideline values and thresholds. Exposure to carcinogenic compounds is always associated with a cancer risk, since these compounds are characterized by their lack of thresholds, i.e. any exposure, in principle one molecule, may cause cancer. We have shown that there are carcinogens (PAH, arsenic, nickel) in the ambient air that may reach exposure levels that will increase the 1:10,000 person risk. The definition of a high-risk community is a risk management definition, of what is acceptable and what constitutes a high/unacceptable risk. It is well-known that the environment does impact the cancer risk in the general population, and that air pollution, all other factors being equal, is the most significant vector for environmental cancer risks. Moreover, that the main exposure route is thus the respiratory system and the greatest risk is thus lung cancer. The cancer incidence rates for lung cancer is relatively low in Gibraltar compared to the rest of the EU (Figure 3.17-3.19, page 63-65), suggesting that other countries are typically of greater risk for lung cancer and that Gibraltar therefore is a relatively lower-risk community.

3. *Is there a correlation and possible causation between observed environmental pollutants and increased incidence rates of cancer*?

**Re 3**) The causation of cancer is complex, multi-causal and long term. At a societal level the cancer incidence rate is highly dependent upon age-structure and demographics. Breast cancer is the cancer type that has the most significant relative elevated cancer incidence rate in Gibraltar compared to the rest of the EU. The causes of breast cancer are multiple, hereunder air pollution (Breast cancer fund, 2010). As pointed out in relation to the above questions Gibraltar has relatively normal range cancer incidence rates, and the environmental exposures are also within the normal ranges for urban European environments. There are exposures to carcinogens, like in most other areas in the EU, and these will increase the risk cancer as they do in the rest of the EU. However, quantifying the correlation and assigning causation is currently not supported by the available data U.S. Presidential Cancer Panel, 2010).

4. *Is there an increased rate for a certain type of cancer that could be linked to environmental pollutants*?

**Re 4**) The direct comparability of the cancer incidence rates is impaired for most of the minor cancer types due to small numbers in Gibraltar (typically 0-2 cases per year). Hence, we can primarily compare the few larger cancer types that combined represent >50 % of the total cancer incidences. The larger cancer types incidence rates were generally relatively low in Gibraltar compared to the rest of the EU, with breast cancer as the exception, which is in the upper centiles among EU countries. The relatively elevated breast cancer incidence rate (elevated compared to the rest of the EU, but still within the normal range) is potentially linked to the exposures to priority pollutants such as PAH, arsenic and nickel via air which will contribute to the cancer risk in general, hereunder breast cancer.

5. *What is the pathway for exposure, e.g. drinking water or air pollution*?

**Re 5**) The primary exposure route is air, with PAH, arsenic and nickel, and potentially chromium as the priority pollutants (Table 4.1, page 84).

6. *If there are environmental cancer risks due to pollutants are these related to specific activities in the area*?

**Re 6**) The primary emitters of carcinogenic air pollutants are the nearby industries. Currently un-quantified emissions from local road traffic, ship traffic, local diesel generators and CEPSA flaring in Spain also contribute. CEPSA, Acerinox, Interquisa, Petresa, Lubricantes del Sur, Edar de la Linea de la Concepcion are the primary quantifiable emission sources for the recorded ambient air carcinogens.

## 6.1 Perspectives

Since 1990, global cancer incidence has risen by 19 %; there are 2.9 million new cases and 1.7 million cancer related deaths each year in Europe. In the developed part of the world 50 % of men and 30 % of women can expect to develop cancer during their lifetime. Hence, cancer remains an important global public health problem. Childhood cancer (0-19 yrs) represents about 1 % of the total cancer cases in the EU, in Gibraltar the Figure is on average 0.5 % (range 0 to 2.1 %). Children are especially susceptible to involuntary environmental exposures to carcinogens, in the UK the overall rate cancer incidence for the 0-19 year old increases by 1.5 % per year (Belpomme et al. 2007). Leukemia is a significant childhood related cancer type we did not see an increase in leukemia over time in Gibraltar (only two cases, one in 2005 and one in 2006). The aetiology of cancer is complex (Hanahan & Weinberg, 2000) the role of the involuntary exposures to many carcinogens in the environment, such as air pollutants, contributes to the rising trend in cancer incidence in urban and high-income areas. The origin of many cancers cannot be restricted to lifestyle-related factors, but in addition to these factors, depends on many environmental factors including viruses, radiation and chemicals, hereunder air pollutants (Belpomme et al. 2007). The exact contribution of the environment to the cancer burden is context depended and being debated, but it is most likely at this time point underestimated (U.S. Presidential Cancer Panel, 2010). Addressing the combined effect of carcinogenic stressors (a part from combined as additive effects) in a reliable and quantitative way is still something for the future.

Direct comparison of cancer incidence rates is complicated by the following aspects. When comparing cancer incidence rates across the EU and between countries, there are at least three significant factors that bias the comparison:

- Population size – the size of the population and hence the statistical robustness of trends in incidence rates
- The age structure of the population – increasing age equals significantly increased cancer incidence rates
- The method used to derive the incidence rates. Some countries, e.g. the Nordic countries, have like Gibraltar actual cancer registries, whereas other countries, e.g. Spain model their incidence rates based on cancer mortality data

The two first factors are difficult to change, but the third is not. Sound cancer screening and monitoring, and effective cancer registry data collection will, all other being equal, result in better detection of cancers and thus a relative increase in the recorded incidence rates for those countries, for example the Nordic countries and also Gibraltar. Thus, the need to compare to the range of all EU countries. A direct comparison between e.g. Spain and Gibraltar is methodologically biased since Spain does not have a national cancer registry. An alternative is to compare between few very carefully selected countries with similar cancer detection and registry methods, similar demographics, and similar population size (*e.g.* within the Nordic countries). These bias factors also impact the comparison between Gibraltar and the rest of the EU.

Breast cancer is of special concern, not only in Gibraltar, but globally. There is a strong link between endocrine disrupting compounds (EDCs), such as different pesticides, flame retardants, plastiziers, building materials, and other consumer products and breast cancer (Breast Cancer Fund, 2010. Most people nowadays spend the majority of their time indoor. Hence, the relative exposure to environmental contaminants, hereunder EDCs, is often higher in indoor air than in outdoor air, warranting more specific analysis of the indoor environment with regards to *e.g.* carcinogens and breast cancer (Rudel and Perovich, 2009).

To better quantify the relative effect of environmental exposure compared to other stressors, i.e. life-style such as smoking, it is beneficial to perform an integrated risk analysis. This will clarify and focus where resources could be prioritized to protect the state of health in the Gibraltar society.

Carcinogens are characterized by not having a threshold, hence assigning a safe exposure is not possible. In these cases we need to assign an acceptable risk. These are based on extensive carcinogenicity and epidemiological studies and are revised regularly by the WHO and IARC. The acceptable risk is based on the lowest reliable toxicity value that represent an excess lifetime risk level for 1 in 10,000 persons, this value can moreover be further reduced relative to the risk aversion by factors of ten typically up to 1: 1,000,000. The acceptable risk is a societal and risk management decision, in this report we provided the starting point with the 1:10,000 risk value. It is clear that the international air quality criteria and guideline values for some carcinogens for practical reasons are set higher than e.g. the 1:1,000,000 cancer risk value, indicating that a risk is accepted.

To obtain a more complete assessment of the potentially critical pollutant sources and their respective contributions to the air quality in Gibraltar it is recommended to consider generating reliable and accurate emission data from local and nearby sources. These include road traffic counts in Gibraltar with vehicle type speciation, and estimated or measured emission factors for road traffic, ship traffic in the Bay and Strait, local diesel generators and flaring from CEPSA. These emission factors should cover identified critical pollutants that are stated in this report.

Even for the industries included in this study there are some potential critical pollutants, e.g. acetaldehyde and formaldehyde, which have not been assessed, since the emitted amounts did not require reporting to the E-PRTR register. Measurement or estimation of emission rates from these industries and modeling of air concentrations in Gibraltar would complement the current risk assessment.

It is recommended to consider the inclusion of chromium along with trichloroethylene and tetrachloroethylene in the current Gibraltar Air Quality Monitoring Programme. Chromium, an IARC class 1 carcinogenic, is assessed to be critical based on conservative exposure modeling of reported emission rates from industries. The lesser carcinogenic trichloroethylene and tetrachloroethylene also exhibit critical air concentrations based on conservative modelling of diffuse emission rates reported from adjacent Spanish municipalities.

Finally, a direct measure of the exposure to priority environmental carcinogens (and other carcinogens) can also be more directly assessed based on a biomonitoring programme in Gibraltar for selected and representative subpopulations.

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