CEMA TB TECHNICAL BROCHURE

STUDY ON EMISSIONS AND THEIR POSSIBLE ENVIRONMENTAL AND HEALTH EFFECTS IN THE SURROUNDINGS OF CEMENT PLANTS

Study done by URS España

› Cement and Environment Labour Foundation ‹

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INDEX

Glossary

2,3,7,8 – TCDD: 2,3,7,8 Tetrachlorodibenzodioxin.

AAC: Air Average Concentration.

AdAC: Admissible Air Concentration.

ADMS: Air Dispersion Modelling System.

ADD: Acceptable Daily Dose by ingestion.

ATSDR: Agency for Toxic Substances and Disease Registry.

CERC: Cambridge Environmental Research Consultants Ltd.

CO: Carbon Monoxide.

Cr III / Cr VI: Chromium with valency 3 and 6, respectively.

DED: Daily Exposure Dose.

E-05: Scientific Notation of 1/100 000, it is equal to 0.00001.

HCl: Hydrochloric Acid.

HF: Hydrofluoric Acid.

IEP: Integrated Environmental Permit.

IRE: Individual Risk Excess.

IRIS: Integrated Risk Information System. US EPA data base about the effect to human health due to the exposure against different substances.

NO_2: Nitrogen Dioxide.

NO_x: Nitrogen Oxides.

OCA: Organismo de Control Autorizado por la Administración (Authorized Control Organism).

OEHHA: Office of Environmental Health Hazard Assessment; its aim is the protection and improvement of the environment and human health after the scientific assessment of the hazardous substances.

PCDD: Polychlorinated dibenzodioxins.

PCDF: Polychlorinated dibenzofurans.

PM_{10}: Particles with a diameter less than 10µm.

$PM_{2.5}$: Particles with a diameter less than 2.5µm.

RI: Risk Index.

SO_2: Sulphur dioxide.

TOC: Total Organic Carbon.

TRV: Toxicological Reference Value.

URE: Unitarian Risk Excess.

URE_i: Unitarian Risk Excess by inhalation.

URE_o: Unitarian Risk Excess by ingestion.

US EPA: United States Environmental Protection Agency.

WHO: World Health Organization.

1 000: One thousand units.

0.1: One tenth (1/10).

Non-technical summary

BACKGROUND

The CEMA FOUNDATION, in which the Spanish Cement Association (OFICEMEN) and the two main trade unions at Spain (FECOMA-CCOO and MCA-UGT) are represented, has decided to undertake a study on the emissions and their possible effect on the environment and health in the surroundings of cement plants. Consequently, the scope of this study goes beyond simple legal obligations, which are currently focused on the control of emissions and its comparison with European standards. Instead, this analysis springs from the commitment that these institutions have to develop their industrial activities with a high level of safety and health protection of workers and people living around the factories.

AIM OF THE STUDY

The aim of this study is to analyze the possible health hazards for those citizens who live in the surroundings of the cement plants.

CEMENT FACTORIES SELECTED

In order to undertake this study, four cement factories of the following company groups have been selected:

- Castillejo factory (Castilla -La Mancha). Cemex España, S.A.
- Montcada factory (Cataluña). Lafarge Cementos, S.A.
- Vallcarca factory (Cataluña). Cementos Portland Valderrivas, S.A.
- Lorca factory (Murcia). Holcim España, S.A.

Three main criteria were applied for the selection of the studied plants:

- **Different geographical locations.**

  In order to complete a comprehensive analysis, different environmental landscapes (natural, rural, industrial and urban) and demographic characteristics of the surrounding areas of plants were taken into account. While the Vallcarca factory is situated in a protected natural area and about 200 meters from the Mediterranean Sea, the factory of Montcada is located in the centre of that municipality, which has a population of more than 30 000 inhabitants. Furthermore, the factory of Castillejo is located in an area of low population

density where dry-farming is predominant, while the factory of Lorca is situated in an industrial area with irrigated crops.

- **Use of different types of fuel for the kilns.**

  Although the main fuel used in all the plants is the petroleum coke, three of the plants studied are also using fuels derived from waste materials in different percentages, which partly replace the petroleum coke. In the particular case of the Lorca factory, they use liquid fuel (solvents, hydrocarbon wastes, rejection of oil recovery, sewage sludge, etc.), whereas the factory of Castillejo uses animal meal, as well as tires and plastic. The Vallcarca factory only uses sewage sludge. Alternatively, at the time of the study, the factory of Montcada did not use any alternative fuel.

- **Representation.**

  The four factories selected, belonging to the cement groups Cementos Portland Valderrivas, Cemex España, Holcim España and Lafarge Cementos, can be considered as representatives of the remaining plants in the Spanish cement sector because of the technology, their emissions and associated control systems.

METHODOLOGY USED FOR THE STUDY

The methodology used for the study is internationally proven and based on the principles employed by the French Administration for the human health risk analysis, and the one used by the U.S. Environmental Protection Agency.

It is a complex methodology which covers the following steps:

1. **Information about the plant and its surroundings:** At this stage, URS has compiled data on the natural and human surroundings of the factory, the climatology of the area, the existing infrastructure, the production process and pollution control systems, among others.

   Furthermore, during this first stage "receptors" were selected, for each of the four factories. Those are the locations of groups whose exposure level is assessed: schools, social centres, parks, etc. These receptors include adults, children and senior citizens people, also called "sensitive receptors".

2. **Information on atmospheric emissions from the factories kilns.** Representative emission averages have been compiled from the respective companies throughout a year. In addition, in order to assess the hazards, we have considered the limits of the Integrated Environmental Permit from the Directive 2000/76/EC and the Royal Decree 653/2003, as the worst scenario (when the plants are emitting the maximum quantity of pollutants allowed by the environmental authorization).

3. **Exposure assessment.** For a better understanding of this stage it is necessary to introduce the concept of risk. Risk is defined as the likelihood that a certain exposure results in an adverse effect. Therefore, to assess the exposure and subsequent risk, it is necessary to analyze the different phases that each pollutant passes through as it is delivered to the atmosphere. The pollutants are dispersed in the air and deposited on the ground so that people around the factory may be affected by the following exposure routes:

   - **Inhalation (breathing the air of the area):** In this case, in order to assess the potential effects related with this route of exposure, two kinds of groups have been defined:

     - People living around the plant, including adults, as what is known as "sensitive receptors" (children and the senior citizens).

     - People who work around the plant.

   - **Ingestion:** The particles present in atmospheric emissions can be deposited on the ground and transferred into the food chain. Therefore, there exist two types of exposure:

     - Direct exposure by ingestion of soil. This exposure refers both to the ingestion of soil present in raw food as well as the accidental ingestion (i.e. this exposure might affect children playing in parks and gardens).

     - Indirect exposure by consumption of food (fruits and vegetables) grown in the area.

The assessments of these two forms of exposure (by inhalation and ingestion) were carried out by international aproved mathematical models.

These mathematical models simulate the dispersion of pollutants on the basis of very diverse data (meteorology, soil features, height of the smokestack) and evaluate the changeover to the receptors.

4. **Risk assessment.** The above models can calculate the amount of pollutants to which a receptor can be exposed. The data obtained by these models are compared with Toxicological Reference Value (TRV), and then some numerical indices are set up to express the risk.

   What is a Toxicological Reference Value (TRV)? It is the highest acceptable concentration of a specific compound that an organism can admit without bearing a negative effect. The TRV used in this study are internationally proven by institutions such as the World Health Organization.

   In case several TRV are available, the most restrictive value (the lowest value) has been selected, following a conservative approach to the study.

   For each pollutant (particles, process gases, heavy metals, etc), an evaluation of potential risk by inhalation or for each of the two exposure routes (ingestion and inhalation) has been done, according to the characteristics of each substance.

CONCLUSIONS

The results of the analysis clearly conclude that emissions of pollutants from the four plants have risk levels much lower than the internationally accepted values considered harmless to the surrounding environment and inhabitants.

For example, the exposure levels obtained for dioxins and furans are between ten thousand (10 000) and ten million times below those defined as safe by the World Health Organization (WHO).

This is especially relevant because the present study has been done with a clear conservative approach, adopting in every phase the situation of worst possible scenario.

It can be concluded that plant emissions do not involve potential health risks to the people in the vicinity of the four cement factories included in this study, even when the maximum emission limits set out in their Integrated Environmental Permit were tested. Furthermore, it can also be determined that the plants that used alternative fuels (instead of petroleum coke) did not involve health risks either.

Chapter 1 Introduction

The aim of this study is to analyze the potential health risks that atmospheric emissions from cement plants may have on people who live around them.

Risk concept can be defined as the likelihood that a certain exposure has an adverse effect. Accordingly, a danger will involve a risk if there is an exposure pathway and this exposure allows the possibility to generate harmful side effects on human health.

Every daily activity has an associated health risk. More specifically, the following table shows the mortality risk related to several common scenarios, such as accidents or serious disease.

Table 1. Examples of risks for human health.

Cause	Dying risk
Lightning struck (or rays)	1/10 000 000[1]
Aircraft accident	1/3 000 000
Road accident	1/10 000
Alzheimer	1/4 500
Lung cancer	1/2 222
Ischemic heart disease	1/1 250

With the objective to minimize the health risks derived from the presence of certain pollutants in the atmosphere, the European Union environmental law is currently very restrictive and specific regarding air quality. These emission limit values were created from other studies and reports that determined the air quality that was necessary for minimal health risk and environmental damage.

The cement industry is committed to monitor, control and comunicate the impacts of the facilities in the environment. Consequently, this report provides in-depth analysis of the impact that industrial activity might have on air quality and over health of workers and people living in the factories' surroundings. Aiming to go beyond legal requirements, the purpose of this report is to focus on the possible effects that the pollutants emitted by the plants may have on human health.

1 One in ten million.

This study has been carried out following a widely proven methodology confirmed by studies done previously in countries such as France and the United States.

In addition, prior to this study[2], URS completed an assessment to CEMA[3] FOUNDATION. This study was done in an effort to obtain the standards, practices, laws and regulations nationally and internationally accepted on this matter.

2 Comparative of the Methodologies of Ecological Description, URS, 2008

3 The CEMA FOUNDATION, is a non-profit-making labour Foundation of peer and tripartite nature, constituted by the Spanish Cement Association (OFICEMEN) and the two main trade unions (MCA-UGT and FECOMA-CCOO). For further information visit: www.fundacioncema.org

Chapter 2 Aim and scope of the study

The aim of this study is to analyze the potential health risks for those citizens who live in the surroundings of the cement plants, resulting from the atmospheric emissions of each studied plant. To make this possible, the following have been completed:

- Determine the emissions of the Spanish cement plants. The studied parameters are those established by the Royal Decree 653/2003, of May 30th, transpose of the Directive 2000/76/EC which regulates the incineration and the co-incineration of waste materials as well as other parameters defined in their Integrated Environmental Permit (IEP) according to the Environmental Spanish Law (IPPC derived).

- An evaluation of the emissions dispersion using a Gaussian mathematic model.

- An evaluation of the potential risks, by the calculation of the risk indices and their comparison with reference values deemed as riskless or of negligible risk. In general terms these values are called Toxicological Reference Values (TRV); they represent the highest acceptable concentration of a particular compound that an organism can admit without bearing a negative effect. The TRVs are expressed in different ways according to the path-way and the sort of exposition. The TRV values are indicated in section 3.4.

In order to undertake this study, four cement factories located in different geographical areas of Spain have been selected, with various environmental landscapes (natural, rural, industrial and urban) and demographic characteristics of the plants' surrounding areas. The plants selected for the study are the following:

- Holcim España factory of Lorca.
- Lafarge Cementos factory of Montcada.
- Cementos Portland Valderrivas factory of Vallcarca.
- Cemex España factory of Castillejo.

Three of the four plants in the study used alternative fuels to feed their kilns. These alternatives fuels were derived from waste materials after preparation in specialized facilities and then arrived at the plant to be energy recovered.

Two operation hypotheses have been considered. First, representative emissions of the plants were assessed.The subsequent scenario is the case that the emissions were at the maximum allowed pollutants quantity established by the environmental authorization. The legally limit values are those from the European Directive 2000/76/EC and the Royal Decree 653/2003, as well as those allowed by the Integrated Environmental Permit (IEP) of each plant.

Chapter 3 Methodology used for the study

The methodology used for the study is based on the analysis of the risks for human health developed by the French Administration, which is also based on publications about risk assessment done by the US EPA[4].

The methodology has the following steps:

- **Description about each plant and its surroundings:** This first stage consists on a preliminary evaluation of each plant and its surroundings. The aim of this first stage is to identify the source of emissions to be considered, gather together and analyse topographic and meteorological data and to identify the potential receptors that could be exposed to the cement plants emissions.

- **Description of the atmospheric emissions:** Once the preliminary evaluation of each plant and its surrounding is done, the next step is to characterize the emissions sources identified before. All the available information related to concentrations and emissions flow, as well as the physical parameters (height, smokestack diameter, etc.) related to each source, was gathered. The study considers the substances included in the Directive 2000/76/EC of waste incineration and also the corresponding Integrated Environmental Permit of each plant.

- **Exposure assessment:** The exposure path-ways considered are inhalation and ingestion. The exposure assessment was done in two phases:

  - Phase I: Atmospheric dispersion modelling with a Gaussian dispersion model, which allows to simulate the pollutants transportation through the air. The model uses the topographic and meteorological data of the studied area to simulate the dispersion of the pollutants emitted.

  - Phase II: Mathematical model to assess the pollutants arrival to the organism after analyzing their evolution in the trophic chain. The initial pollutant concentrations are those calculated in the previous phase. The physical and che-

4 EPA: Environmental Protection Agency of the United States Of America

mical features of the evaluated pollutants were taken into account, as well as their bioaccumulation potential, etc.

- **Risk assessment:** The quantifying of the potential risks was done by comparing the air, soil and food concentration, and the corresponding calculated doses obtained by the different models used, with the Toxicological Reference Values (TRV) for each evaluated compound.

3.1 DESCRIPTION ABOUT EACH PLANT AND ITS SURROUNDINGS

With the aim to identify and characterize the emission sources, and the assessment of the main features of the surrounding areas, URS visited each plant included in the study, gathering together data about:

- **Production process:** Type of emission sources and characteristics of them, annual production and incidents occurred during the production process (shutdowns for maintenance, equipment replacement, etc…).

- **Emissions measuring system:** Characteristics of the gouges, equipments calibration and external controls.

- **Natural environment:** Physic and biotic environment, protected zones, climatology of the zone and air quality.

- **Human environment, infrastructure and inhabitant units/settlements:** The most sensitive receptors were defined according to: wind rose, the vicinity to the plants and the population characteristics (potential risk groups as residents, workers and kids).

The following table is a summary of the main characteristics related to each plant. As it is shown, the plants have been selected so that the analysis could cover different situations of location (rural or urban landscape), fuel (petroleum coke or alternative fuels), relief and climatology.

Table 2. Description of each factory included in the study.

Factory	Location	Surrounding	Climatology	Manufacture technology and production capacity	Fuel used
Holcim España	Lorca	Located inland. Relatively close to a large population (2 km) and farm zone Dispersed factories around	Mediterranean weather, hot and semi-hot subtropical	Dry clinker kiln 600 000 tons of clinker per year	Traditional fuel (petroleum coke, carbon) and alternative fuels (fuel recovered from the waste of hydrocarbon, solvent, impregnated sawdust, sewage sludge)
Lafarge Cementos	Montcada	Located in the inland. Closeness to a population area (500 m). High density of factories, next to motorways	Mediterranean weather dry – semi - wet	Dry clinker kiln 700 000 tons of clinker per year	Traditional fuel (petroleum coke, carbon)
Cementos Portland Valderrivas	Vallcarca	Dispersed population. Close to many population settlements (2 to 10 km). No factories around. Located in the coast near a natural park	Mediterranean weather dry – semi - wet	Dry clinker kiln 1 150 000 tons of clinker per year	Traditional fuel (petroleum coke, carbon) and alternative fuels (sewage sludge)
Cemex España	Castillejo	Located in the inland. Rural landscape, (settlements at 3.8 and 6.8 km). No factories around	Continental Mediterranean weather	Dry clinker kiln 1 500 000 tons of clinker per year	Traditional fuel (petroleum coke, carbon) and alternative fuels (tires, plastics, animal meal)

3.2 DESCRIPTION OF THE ATMOSPHERIC EMISSIONS

3.2.1 Considered parameters

The parameters considered in the study are those established by the **EU Directive 2000/76/EC and Spanish Royal Decree 653/2003 about the incineration (and co-incineration) of waste materials**. The latter regulates the monitoring and the emissions control of the clinker kiln of the following substances and compounds:

- Gases: NO_x, SO_2, TOC, HCl, HF, CO.
- Total particles.

- Dioxins and furans (PCDD and PCDF).
- Metals: Antimony, Arsenic, Cadmium, Cobalt, Copper, Chromium, Mercury, Manganese, Nickel, Lead, Thallium, Vanadium.

Therefore, the modelling considered the kilns of each factory as a source of emissions.

In some cases the Zinc and Tin parameters were included because they were regulated by the IEP of the factory.

3.2.2 Emissions values considered

The study considered the following scenarios in each factory:

- **Scenario 1:** Assessment of the potential risks related to the production of each factory analysing the composition and flow of the emissions.

- **Scenario 2:** Assessment of the potential risks supposing as emission values the emission limit values regulated for the plant.

Emission values of the factories

The aim of this part of the study was to analyse the impact of the pollutants emitted while the factories are working. Therefore, it was necessary to select representative emissions data of a common operation of the factories. The selected and analysed data were taken from the last years. Generally, the last two years data were selected because those are more representative.

- Emission flow. Generally the flow of the last two years was used because those values are closely representative of the plant's production.

- Gases (NO_x, SO_2, TOC, HCl, HF, CO) and total particles. In general, it was considered the average calculated from the continuous monitoring system.

- Dioxins, furans and metals. It was considered the average calculated from the measurements done by the Authorized Control Organisms (ACO) during 2007-2008.

In addition, in order to establish the emission values of every factory, for each substance or tracer the following assumptions were made:

- For the modelling of the nitrogen oxides (NO_x), those were expressed in NO_2 equivalent.

- In the case of the Chromium, measurements provided just the total Chromium values. In order to analyse the effects of this metal in its two oxidation states (Cr III and Cr VI) an estimation has been done to separate the emissions of Cr III and Cr VI. The criterion selected was the distribution of the metal in the raw material, which is around 30% in Cr VI. Therefore, based in the chromium analysis, the quantities of 70 % for Cr III and 30 % for Cr IV were taken.

- According to the Directive 2000/76/EC, the dioxins and furans must be expressed as 2,3,7,8 – TCDD (Tetrachlorodibenzodioxin), because it is the most toxic compound. Therefore, for the determination of the dioxins and furans concentration it was necessary to multiply by the toxic equivalence factor before summing. The group of these compounds is also assimilated to a unique tracer in physic and chemical parameters for the assessment of the transfer in the food chain. These entire hypotheses overestimate the potential risk, because if the potential risk of every compound of the dioxins and furans family is considered separately, the risk index would decrease substantially.

Emissions limit values

For the determination of the emission limit values those established by the Directive 2000/76/EC and the Royal Decree 653/2003, as well as the limits established by the Integrated Environmental Permit (IEP) of each factory were considered. For those parameters not regulated neither by the Directive or the Royal Decree and not included in the IEP, the following criterion was used:

- Metals. Except in the case of mercury, the limits established by the Directive 2000/76/EC and by the Royal Decree 653/2003 are expressed as a sum. Namely, it is established that the addition of the concentration of a group of metals emissions can not be over a determined value. Therefore, with the purpose of taking a maximum hypothetic value for each metal, estimation has been done according to the weight of every compound of the real analytic of each factory,

when the data was available. When data was not available, the limit value for each metal that has been taken is the one which corresponds to the sum.

3.3 EXPOSURE ASSESSMENT

The exposure path-ways considered are inhalation and ingestion.

The people who live and/or work around the plants included in the study are potentially exposed directly to inhalation of air, due to the atmospheric emissions from the plants.

For the evaluation of the **inhalation effects**, two kinds of receptors were distinguished:

- People living around the plant (residents). The adults, children and senior citizens are included in this group of receptors, named sensitive receptors. The risk assessment assumes that the people who live around the plant are exposed to the emissions during 24 hours per day.

- People who work around the plant. This receptors group includes the working-age people that are exposed to the atmospheric emissions during the workday. The risk assessment assumes that the people who work around the plant are exposed to the emissions for approximately 8 hours per day.

The exposure assessment by inhalation considers both the effects related with the particles inhaled and those related with its chemical composition. Therefore, for this exposure assessment all the compounds selected as tracers for the study (see table 3) were taken into account.

Moreover, the particles that are in the atmospheric emissions can deposit and accumulate on the ground. This is called deposition. Consequently, the risk of contamination can come either from the ground soil or from the food chain, it depends on the particles, the deposited quantity and the physic and chemical features of the soil.

The assessment by **ingestion exposure** was done for those substances both sedimentary and bio-accumulative in the food chain. Therefore, the compounds that were considered are metals, dioxins and furans.

Two kinds of exposures were considered:

- Direct exposure by soil ingestion. This mainly affects children who play at parks, gardens and other outdoor places where they can ingest soil particles.

- Indirect exposure by consuming the foodstuffs from the area where the compounds sedimentation has taken place.

3.3.1 Phase I: Atmospheric dispersion modelling

The estimation of the pollutant air concentrations has been done with mathematical modelling of atmospheric dispersion ADMS 4.0, software distributed by CERC (Cambridge Environmental Research Consultants Ltd.).

The model estimates the average concentrations of each parameter of every defined point. In addition, those parameters that can deposit on the soil have a mass deposition rate that is calculated for every pollutant.

The following are the inputs for the model:

- **Emission data:** For the calculation of the emission mass rate of every pollutant the concentrations in mg/Nm^3 on dry basis and corrected in 10% of oxygen were taken, and the flow is expressed in Nm^3/h in the same conditions.

- **Meteorological data:** The meteorological data was taken from the plant's stations, or alternatively, from the nearby stations.

- **Topographical data:** The Digital Terrain Model (DTM) was used to consider the topography for every analysed zone.

- **Receptors:** The analysed receptors had been identified in the field and agreed upon with the plant staff according to the community points of interest.

The inputs of the model for each plant are indicated in the next point.

3.3.1.1 Input data for the model. Holcim España factory of Lorca

Source of emission

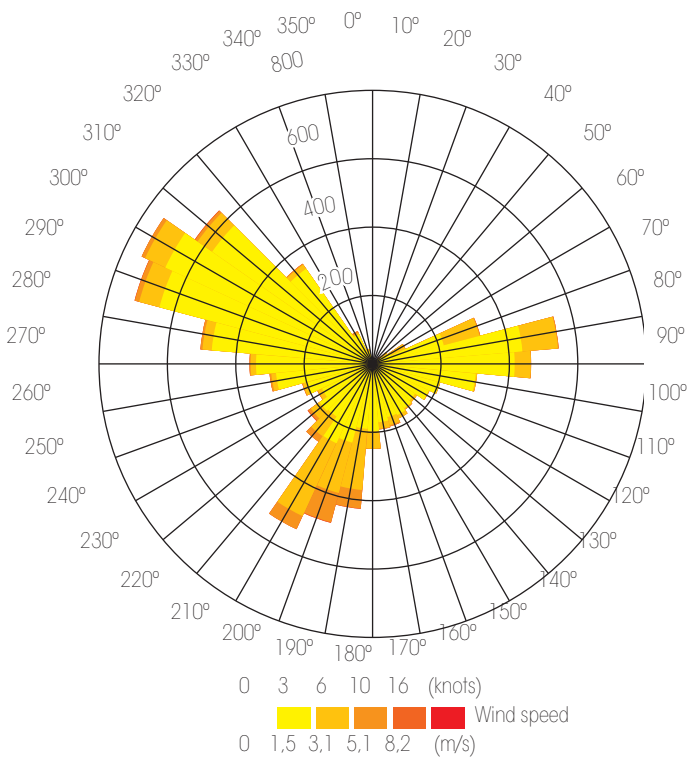
The source of emission considered is the cement kiln, whose emission flow is 199 556 Nm^3/h in dry basis and corrected to 10% oxygen.

Meteorological data

The hourly data of wind direction and speed, temperature and atmospheric humidity have been taken from the web site of the "Comunidad Autónoma de Murcia". The data considered is that belonging to the period from 2006 – 2008.

The wind rose of the Holcim España factory of Lorca for the period of time considered is shown in the following picture:

Figure 1. Wind rose of the Holcim España factory of Lorca.



As shown in the figure above, the prevailing winds come from the northwest, the south and the east. The southern component has the highest wind speed. Therefore, it is likely that most of the dispersion will occur in the northern direction. In other directions dispersion will be lower, so the plume will be focused on the surrounding of the plant.

Receptors

With the purpose to study the possible risks to human health on the people who live/work around the plant, several points of the territory or receptors were selected. In this case the receptors are located at the municipality of Lorca (as seen in the picture below), because it is the nearest inhabited zone to the plant.

In the following pictures is shown the studied area related with the location plant:

Topographical data

Once the receptors are located, the grid for the modelling was defined.

The Digital Terrain Model (DTM) of the zone was used. In this case, a square grid of 10 Km x 10 Km was defined.

Figure 2. Studied area considered for the modelling. Factory of Lorca (Holcim España).

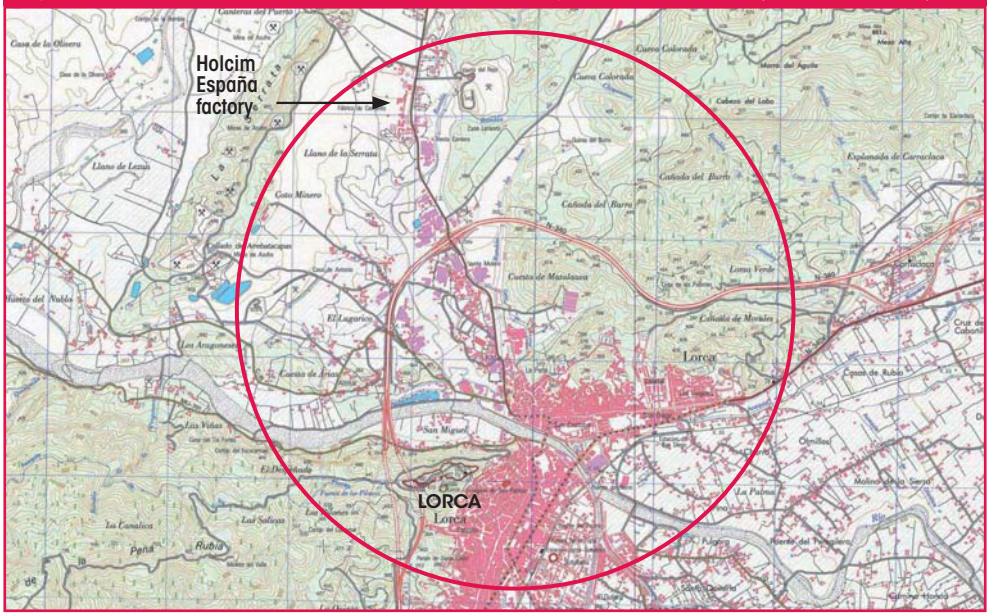
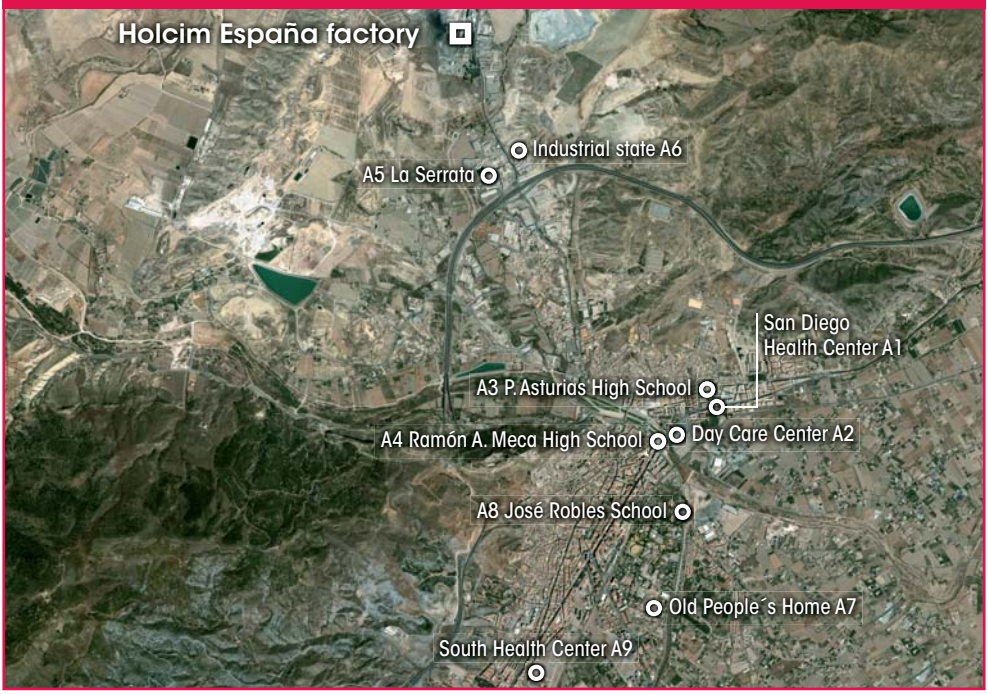


Figure 3. Orthophoto of the studied area considered for the modelling. Factory of Lorca (Holcim España).



3.3.1.2 Input data for the model. Lafarge Cementos factory of Montcada

Source of emission

The source of emission considered is the cement kiln, which has an emission flow of 175 000 Nm^3/h in dry basis and corrected to 10% oxygen.

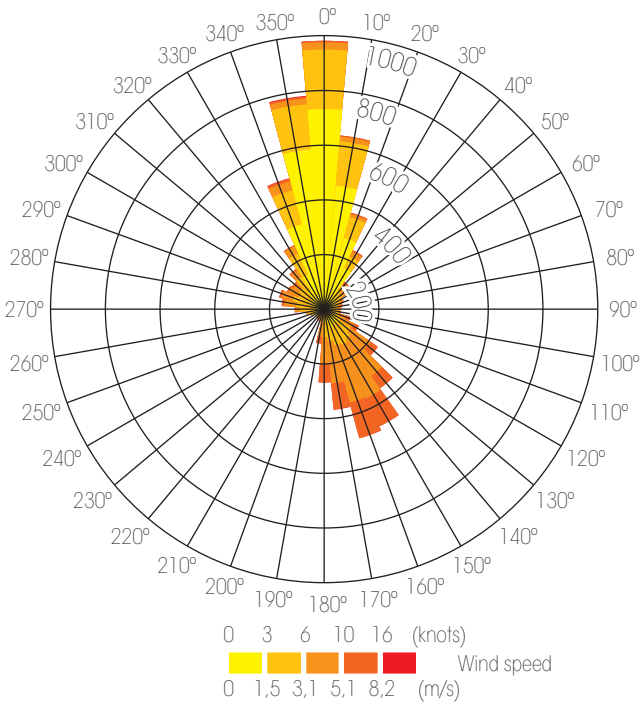
Meteorological data

The hourly data of wind direction and speed, temperature and atmospheric humidity have been given by Xarxa de Vigilància i Prevenció de la Contaminació Atmosférica de Catalunya (XVPCA), and belong to the station located in the municipality of Montcada i Reixac for the period from 2002-2005. The station did not have up to date meteorological data, given that only inmission pollutant concentrations were measured by the station since 2005. For the relative humidity and cloud estimation the station data of Cerdanyola del Vallés have been considered, due to its proximity to the plant.

The wind rose of the Lafarge Cementos factory of Montcada for the period of time considered is shown in the following picture.

As shown in the figure, the prevailing winds came from the north and southeast. This last one registered the highest wind speed (up to 8 m/s). Therefore, it is likely that the dispersion will occur on south and northwest directions, mainly across the northwest. The plume will be focused on the plant surroundings.

Figure 4. Wind rose of the Lafarge Cementos factory of Montcada.



Receptors

With the purpose to study the possible risks to human health on the people who live/work around the plant, many points of the territory or receptors were selected. In this case the receptors are located both at the municipality of Montcada i Reixac and those close to it.

Topographical data

Once the receptors are located, the grid for the modelling was defined.

The Digital Terrain Model (DTM) of the zone was used. In this case, a square grid of 7 Km x 7 Km was defined.

Figure 5. Studied area considered for the modelling. Factory of Montcada (Lafarge Cementos).

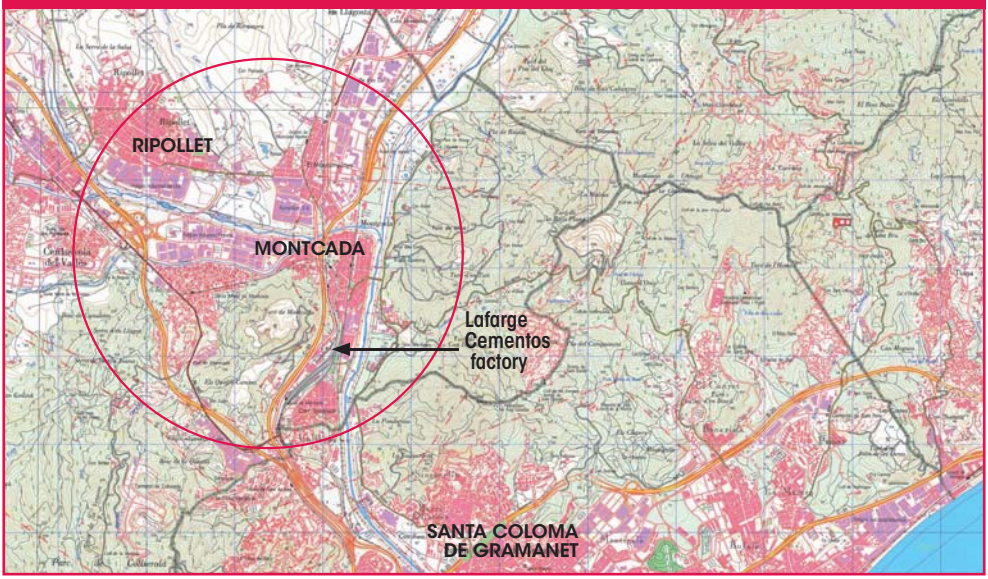
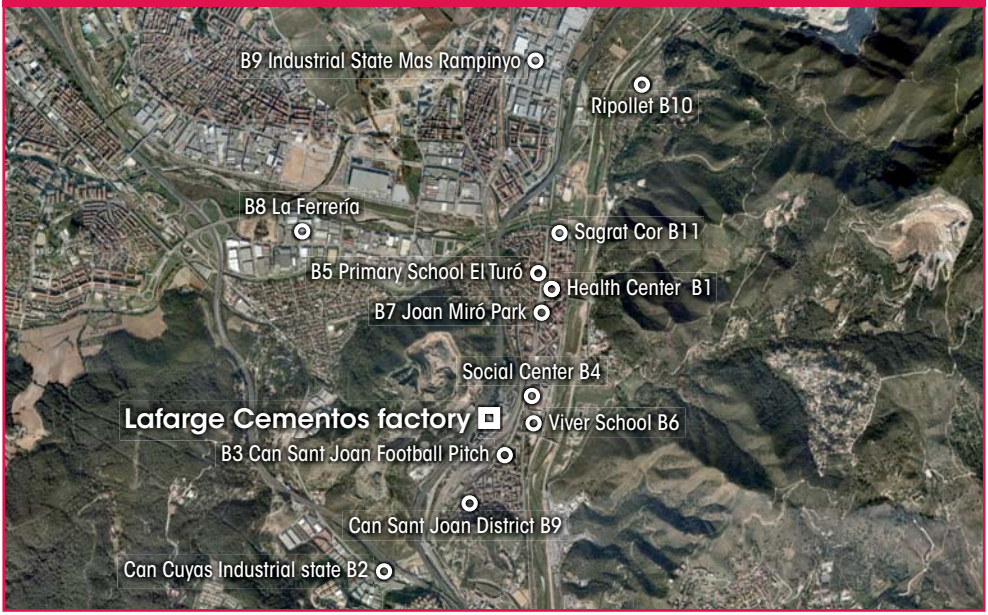


Figure 6. Orthophoto of the studied area considered for the modelling. Factory of Montcada (Lafarge Cementos).



3.3.1.3 Input data for the model. CEMENTOS PORTLAND VALDERRIVAS factory of Vallcarca

Source of emission

In the Cementos Portland Valderrivas factory of Vallcarca there are two cement kilns, with a flow of 199 201 Nm^3/h (Kiln VI) and 336 230 Nm^3/h (Kiln VII), both with a dry process and corrected to 10% oxygen.

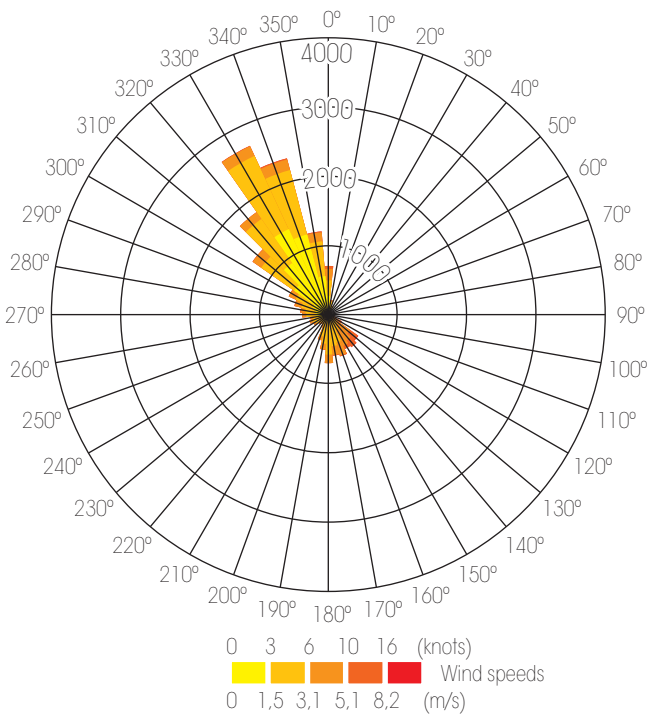
Meteorological data

The hourly data of wind direction and speed, temperature, atmospheric humidity and solar radiation have been given by the plant itself according to the measurement completed by their own meteorological station (Model EM-300 of the brand MCV S.A) located at the plant.

The wind rose of the CEMENTOS PORTLAND VALDERRIVAS factory of Vallcarca for the period of time considered is shown in the Figure 7.

As shown in the figure above, the prevailing winds come from the northwest, with a small contribution from the southeast component. Therefore, it is likely that the dispersion will occur in the southeast and northwest.

Figure 7. Wind rose of the Cementos Portland Valderrivas factory of Vallcarca.



Receptors

With the purpose to study the possible risks to human

Figure 8. Studied area considered for the modelling. Factory of Vallcarca (Cementos Portland Valderrivas).

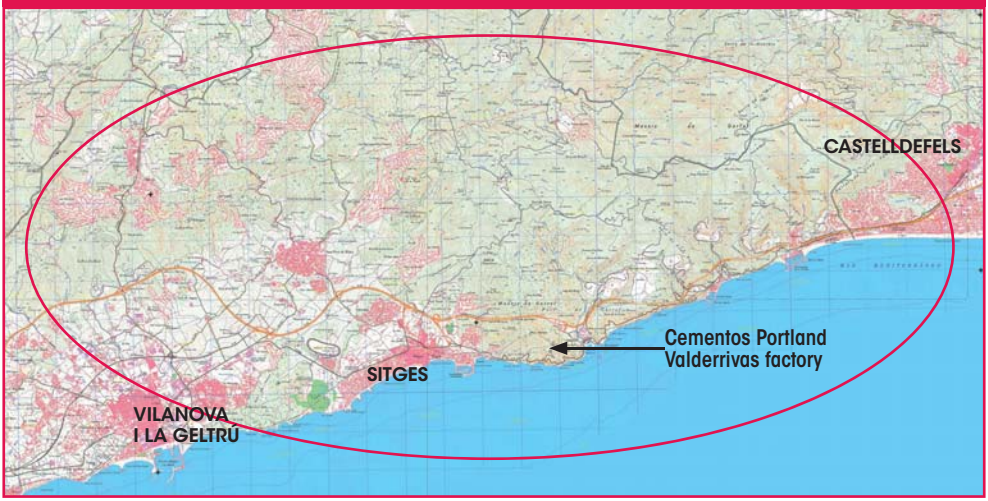


Figure 9. Orthophoto of the studied area considered for the modelling. Factory of Vallcarca (Cementos Portland Valderrivas).

health on the people who live/work around the plant, many points of the territory or receptors were selected. In this case the receptors are located between 2 and 12 km from the plant.

Figures 8 and 9 illustrate the studied area related to the location plant:

Topographical data

Once the receptors are located, the grid for the modelling was defined.

The Digital Terrain Model (DTM) of the zone was used. In this factory, a grid of 18 km x 8 km was defined, adapting the grid to the presence of the coast.

3.3.1.4 Input data for the model. Cemex España factory of Castillejo

Source of emission

In the Cemex España factory of Castillejo there were two cement kilns, with a flow of 251 168 Nm^3/h (Kiln V) and 248 648 Nm^3/h (Kiln VI), both with a dry basis and corrected to 10% oxygen.

Meteorological data

The hourly data of wind direction and speed, temperature, atmospheric humidity and solar radiation were given by the meteorological station located near the cement plant.

Figure 10. Wind rose of the Cemex España factory of Castillejo.

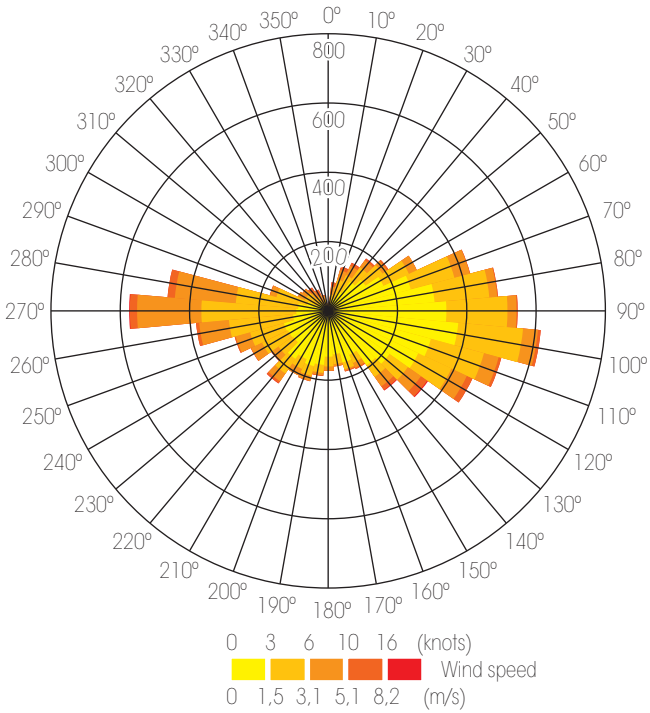
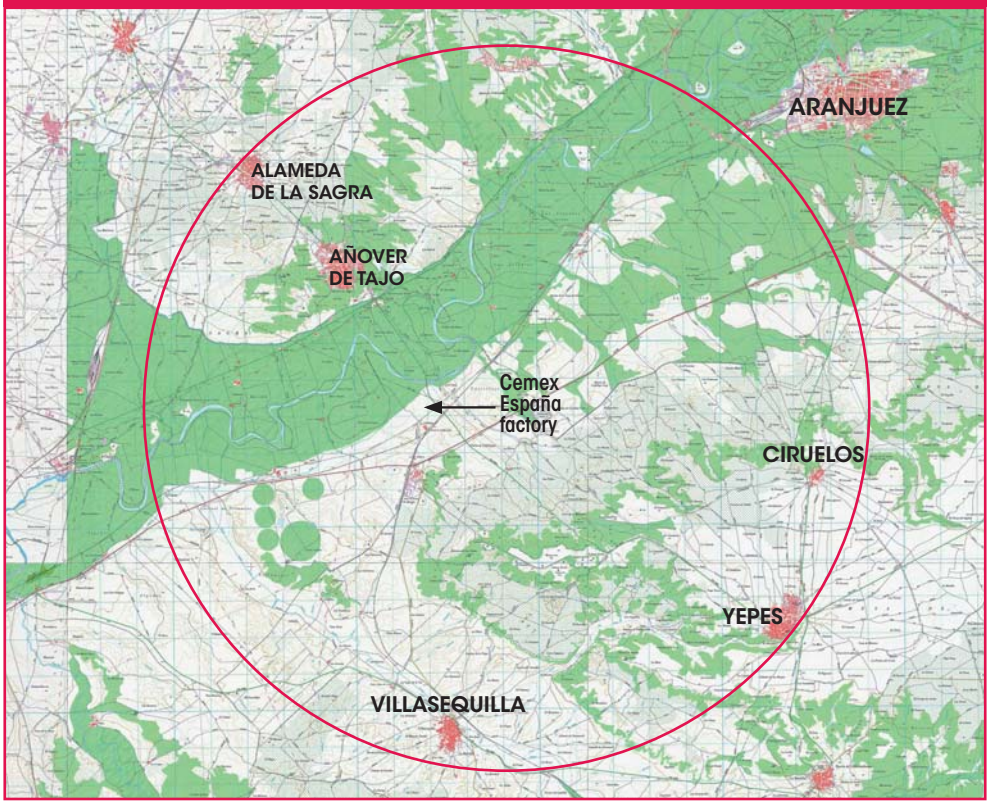


Figure 11. Studied area considered for the modelling. Factory of Castillejo (Cemex España).



The wind rose of the Cemex España factory of Castillejo for the period of time considered is shown in the Figure 10. The prevailing winds come from the east and west; the west-east component has the highest speed. Therefore, it is likely that the dispersion will occur in the east and west direction, while in the other directions this will be lower and the plume will be focused on the plant surroundings.

Receptors

With the purpose to study the possible risks to human health on the people who live/work around the plant, many points of the territory or receptors were selected. In this case the receptors are located between 0.5 and 11 km to the plant.

The following pictures illustrate the studied area related with the location plant:

Topographical data

Once the receptors are located, the grid for the modelling was defined.

The Digital Terrain Model (DTM) of the zone was used. In this case, a square grid of 22 Km x 22 Km was defined, so all the municipalities identified as potential receptors are included.

Figure 12. Orthophoto of the studied area considered for the modelling. Factory of Castillejo (Cemex España).

3.3.2 Phase II: Ingestion Model

The ingestion model is an analytical model based on kinetic equations published by the US EPA, in which assesses every compound's is transfer by the food chain. The assessment is done with the deposition rate for every compound determined with the dispersion model.

The reference documents used are the following:

- US EPA, 2005. Human Risk Assessment Protocol for Hazardous Waste Combustion Facilities, USEPA Office of Solid Waste Emergency Response (OSWER), EPA520-R-05-006.

- US EPA, 1994. Estimation Exposure to Dioxin-Like compounds. EPA/600/6-88/005Cc. Office of Research and Development, National Centre of Exposure Assessment, Washington DC.

- United States Environmental Protection Agency, 1991. Risk Assessment Guidance for Superfund: Volume I – Human Health Evaluation Manual (Part B, Development of Risk-Based Preliminary Remediation Goals. Office of Emergency and Remedial Response, Washington, DC.

- Radiation Site Cleanup Regulations: Technical Support Document for the Development of Radiation Cleanup Levels for Soil (EPA 402-R-96-011 A).

3.4 POTENTIAL RISK ASSESSMENT

3.4.1 Previous concepts

The risk evaluation includes a comparison between the exposure level of the receptor and the internationally recognized reference values. Therefore, it is necessary to obtain the knowledge of the following concepts:

- Health effects.

- Toxicological Reference Value (TRV).

3.4.1.1 Emissions effects on human health

There are two kinds of effects on health:

Effects related with the substances with threshold

This belongs to those effects related with substances that, according to the state of art information, do not represent a significant health risk when they are in the environment under a specific concentration (threshold concentration).

In those effects with threshold, the potential risk level is assessed by a direct comparison between the exposition and the threshold value and, it is expressed like risk index (RI = exposition/Threshold). So, a Risk Index equal to 1 represents the threshold under which there is not risk for human health.

Effects related with the substances without threshold

The effects related with the substances without threshold are stochastic or probabilistic. This means that a probability exists in which adverse effects may appear when a human is exposed to any of these substances. These effects are genotoxic, consequently the carcinogenic and mutagenic substances are usually included in this group. Therefore, the effects related with substances without threshold are often called carcinogenic.

The risk of development of adverse pathology due to a specific compound exposure is calculated with the **Individual Risk Excess** (IRE) parameter. The IRE is initially calculated from the Unitarian Risk Excess (URE), that represents the likelihood that a receptor can be affected by a certain effect of the substance if is exposed to a unit concentration of it. The URE values of each substance were taken from internationally recognized values.

In this study, for the Individual Risk Excess (IRE) it was considered as reference value 1/100 000 (10^{-5}), according to the common guideline of the studies of risk. So an IRE equal to 1/100 000 means that one person out of 100 000 could develop an adverse pathology due to a pollutant substance exposure.

It is worth mentioning that some substances, like arsenic, have defined toxicological values related with the effect with and without thresholds (see table 3).

In the case of the dioxins, only effects with a related threshold value were considered. The dioxin TCDD, the most toxic group of the congeners, is classified by the IARC[5] as "human carcinogenic". Due to the classification of TCDD as carcinogenic, the group of dioxins and furans are classified like it too. Although these compounds are considered as carcinogenic, they do not have a genotoxic mechanism, consequently they do not

5 The International Agency for Research on Cancer (IARC), a cancer branch of the World Health Organization (WHO), did at 1997 a TCDD evaluation.

affect the genetic material. This allowed to establish a toxicity threshold value, below which, the exposure does not have harmful consequences for human health. The scientific society agrees with this point. Therefore, these compounds are classified as substances with a related threshold value.

3.4.1.2 Toxicological Reference Values (TRV)

The Toxicological Reference Values are the highest acceptable concentration of a compound that an organism can admit, without bearing a negative effect.

The Toxicological Reference Values used in this study belong to different data base published by specialized scientific organism (US EPA, ATSDR, WHO, etc.) and others internationally recognized.

For those substances that have an effect when they reach the threshold value, the available data have been verified, to remove the uncertainty for the election of the TRV according to the exposure considered.

For those substances without threshold value, the data published by the specialist organism do not allow, in general, to make a TRV ranking from the assessment of the related uncertainty. Therefore, an over estimate approximation was selected for the assessment of the potential risks, taking the most conservative value.

Table 3 is a summary of the toxicological values with each tracer according to the exposure path-way used in this study. The TRV from the table are the followings:

- AdAC ($\mu g/m^3$): Admissible Air Concentration.
- URE_i $(\mu g/m^3)^{-1}$: Unitarian Risk Excess by inhalation.
- ADD (mg/kg/day): Acceptable Daily Dose by ingestion.
- URE_o $(mg/kg/day)^{-1}$: Unitarian Risk Excess by ingestion.

Given that TOC (Total Organic Carbon) is not a parameter, it has not TRV related. Therefore, it was not included in the analysis of potential risks. Organic pollutants risk was addressed for dioxins and furans.

Table 3. Toxicological Reference Values used.

Parameter	INHALATION				INGESTION			
	AdAC (µg/m³) (with threshold)	Ref	URE_i (µg/m³)$^{-1}$ (without threshold)	Ref	ADD (mg/kg/day) (with threshold)	Ref	URE_o (mg/kg/day)$^{-1}$ (without threshold)	Ref
NO_X	4.00E+01	1	-	-	-	-	-	-
SO_2	2.00E+01	1	-	-	-	-	-	-
TOC	NA	-	-	-	-	-	-	-
HCl	2.00E+01	2	-	-	-	-	-	-
HF	1.40E+01	3	-	-	-	-	-	-
CO	10 000	1	-	-	-	-	-	-
PM tot	20	1*	-	-	-	-	-	-
Dioxins and furans	4.00E-05	4	-	-	1.00E-09	17	-	-
Sb	1.40E+00	5	-	-	4.00E-04	5	-	-
As	3.00E-02	6	3.30E-03	13	3.00E-04	18	1.50E+00	23
Cd	0.02	6	1.80E-03	14	1.00E-03	19	-	-
Co	1.00E-01	7	-	-	-	-	-	-
Cu	1.00E+00	8	-	-	-	-	-	-
Cr III	60	8	-	-	-	-	-	-
Cr VI	0.1	9	4.00E-02	15	-	-	-	-
Mn	5.00E-02	10	-	-	-	-	-	-
Hg	3.00E-01	11	-	-	-	-	-	-
Ni	9.00E-02	12	3.80E-04	15	-	-	-	-
Pb	5.00E-01	1	1.20E-05	16	3.57E-03	20	8.50E-03	24
Tl	NA	-	-	-	6.98E-05	21	-	-
V	NA	-	-	-	3.00E-04	22	-	-
Sn	7.00E+03	25	-	-	2.00E+00	27	-	-
Zn	1.05E+03	26	-	-	3.00E-01	28	-	-

1 Royal Decree 1073/2002
1* TRV for PM is taken equal to PM_{10}
2 IRIS, 07/1995
3 CalEPA, 08/2003 (doc 04/2005)
4 CalEPA, 02/2000 (doc 04/2005) (oral route). Dioxin value 2,3,7,8-TCDD
5 IRIS 02/1991 (oral route)
6 INERIS 12/2006: CalEPA, 01/2001 (doc 05/2008)
7 ATSDR, 10/2004, particles (doc 11/2007)
8 INERIS, 2004: RIVM, 03/2001 (insoluble salt y metals)
9 INERIS, 2004: IRIS, 09/2008
10 IRIS, 12/1993
11 IRIS, 06/1995, elementary
12 ATSDR, 09/2005, particles (doc 11/2007)
13 INERIS, 12/2006: Cal EPA, 07/1990 (doc 05/2005)
14 INERIS, 2004: IRIS, 06/1992
15 INERIS 2004: OMS, 1999 (doc 2000, 2ª edition)
16 CalEPA, 04/1997, inorganic (doc 05/2005)
17 INERIS 2004: ATSDR, 12/1998 (doc 11/2007)
18 INERIS 12/2006: IRIS, 02/1993 (inorganic)
19. INERIS 2004: IRIS, 02/1994 (diet)
20 INERIS 2004: OMS, JEFCA, 1999, (PTWI = 25 µg/kg/week) y GDWQ, 2006
21 IRIS, 09/1990, thallium carbonate value (8*10-5, change to thallium)
22 ATSDR, 07/1992, (doc 11/2007, derivative from a subcronic value)
23 INERIS 12/2006: IRIS, 04/1998 (inorganic)
24 Cal EPA, 10/2000, inorganic (doc 05/2005)
25 OMS, JECFA, 2000, inorganic, oral route
26 INERIS 2004: IRIS, 08/2005, oral route
27 OMS, JECFA, 2005, inorganic
28 INERIS 2004: IRIS, 08/2005

3.4.2 Potential risk assessment

The potential risk assessment considered the two exposure path-ways aforementioned, inhalation and ingestion.

For the **inhalation** analysis, the inmission air concentrations of each pollutant defined according to ADMS 4.0 modelling have been considered.

For the **ingestion** analysis, deposition indices for each compound determined by the dispersion model have been evaluated. Those indices were used in the ingestion model developed by US EPA for the assessment of every compound transfer by the food chain. This assessment only considered the soil ingestion, fruits and vegetables because the current system of cattle raising production, the quantity of beef, poultry, eggs and milk production in the area of influence is small compared with the possible ingestion of fruits and vegetables.

The following exposure path-ways were considered for the analysis of the potential risk by ingestion:

- Soil Ingestion. This scenario considers the direct ingestion of the soil of near receptors.

- Ingestion of fruits and vegetables growth for personal consumption. This scenario considers the exposure of all the residents, adults and children, which may eat the vegetables and/or fruits growth nearby the receptors.

Additional factors have also been considered for the assessment:

- Continuous exposure during 30 years.

- Daily consumption of vegetables from particular gardens and in the following groups, tuber (potatoes, carrots), leafy vegetables (spinach, lettuce) and fruit vegetables (tomatoes, courgette). The quantity consumed by adults and children has been obtained from the CIBLEX[6] data base. This hypothesis belongs

6 CIBLEX, June of 2003. Descriptive parameters data base of a French population in a pollutant environment. .

to a theoretical scenario in which the receptors consumed vegetables cultivated for their personal consumption.

With conservative criteria, it has been considered that all the ingested substances are assumed by the receptors, which means a 100% bioavailability of all the compounds.

3.4.2.1 Potential risk assessment for substances with threshold

It is referred to the effects related to substances that, according to the information available until now, do not represent a significant risk to human health when their concentration is under determinate limits.

For those effects that have a threshold, the Risk Index (RI) is calculated from the Air Average Concentration (AAC) and the Admissible Air Concentration (AdAC) for the inhalation exposure, and the Daily Exposure Dose (DED) and the Admissible Daily Dose (ADD), for the ingestion exposure:

$$RI = \frac{AAC}{AdAC}$$

or

$$RI = \frac{DED}{ADD}$$

The risk indices were calculated for each substance and its exposure path-way and then were weighted up according to their exposure time.

The Admissible Air Concentration (AdAC) and Admissible Daily Dose (ADD) are taken from the Toxicological Reference Values (TRV) of each substance.

An individual Risk Index lower than 1, means that the assessed exposure is lower than the threshold obtained from the legal reference, scientific works, etc.

In the inhalation exposure analysis, the TRV's considered correspond to the most sensitive receptors. Therefore, the risk index did not distinguish different population vulnerability because all the receptors have been considered as sensitive.

For the exposure by ingestion, with the aim to analyze the different food practices of adult and child population, both groups were assessed independently.

3.4.2.2 Potential risk assessment for substances without threshold

The effects of substances without threshold are established from the Individual Risk Excess (IRE) parameter, according to the Unitarian Excess Risk by inhalation or ingestion (URE_I o URE_O):

$$IRE = \frac{DED \cdot URE_O \cdot N^o\ Exposure\ years}{Life\ time}$$

or

$$ERI = \frac{DDE \cdot URE_i \cdot N^o\ Exposure\ years}{Life\ time}$$

According to the WHO recommendations, a potential risk is considered acceptable if the IRE parameter is lower than 10^{-5} (1/100 000).

The IRE accounts for the number of years that the exposure last over the life time of an individual. This study has assumed 70 years to be a lifetime. According to the consulted documentation, the lifetime considered in this study is similar to them.

The risk assessment of the effects of substances without threshold was assessed only for adult population because assumes an exposure lifetime of 30 years over a 70 years lifetime.

The following figure shows the followed methodology for the assessment of the potential risk related to each receptor, according to the exposure and parameter considered.

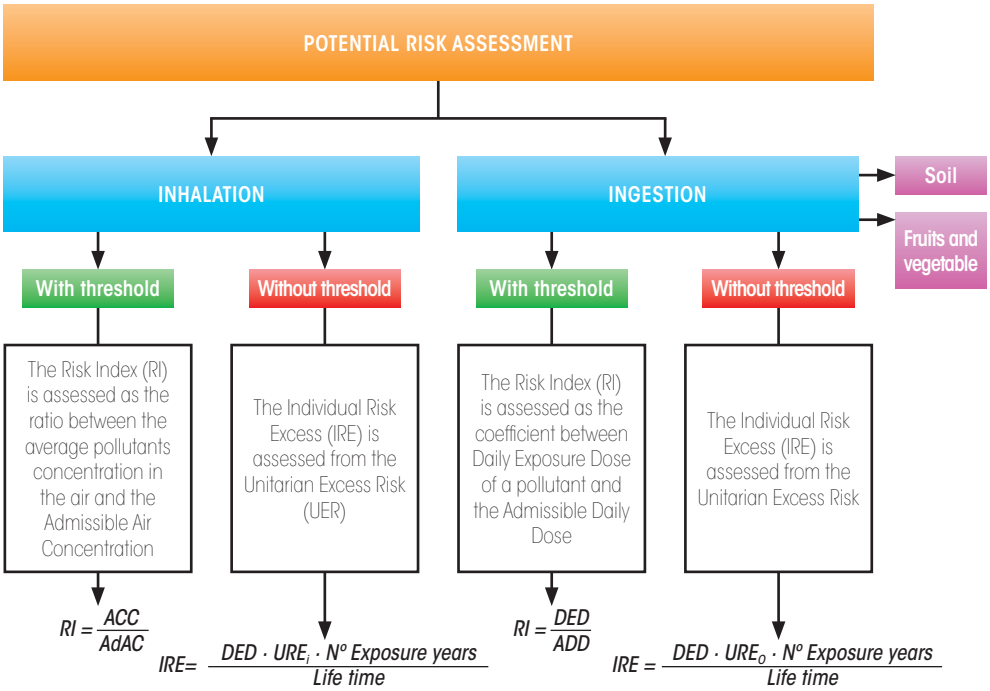
For the assessment of the potential risk of each parameter the following aspects have been taken into account:

- Given that TOC (Total Organic Carbon) is not a parameter, it has not TRV related. Therefore, it was included in the assessment of the emission concentration modelling, but it was not included in the analysis of potencial risks.

- For the total particles it was considered the TRV of the PM_{10}, with conservative criteria for the risk assessment.

- Thalium and vanadium do not have TRV related, so they were included in the assessment of the inmission concentration modelling but were not included in the analysis of inhalation risks.

- Cadmium does not have an URE (Unitarian Risk Excess) related to an oral route exposure, because both the data base of IRIS and OEHHA consider that, with the available information obtained, is not possible to determinate URE value. Therefore, the cadmium was not considered in the assessment of the individual risk excess (IRE) by oral route in the risk analysis.



Chapter 4 Results

For each pollutant or tracer, the annual inmission average concentration has been calculated from the real emissions of the studied plants, and also in the hypothetic case of emissions equal to the legally established. Also, the model provides the mass rate of pollutants deposition on soil.

With all of this data, an inhalation and ingestion analysis has been conducted. The inhalation risk assessment compared the inmission concentration of each pollutant with the corresponding TRV. The ingestion assessment used a kinetic model that calculated the exposure dose of every receptor, due to the deposited pollutants transferred through the food chain.

The following sections show the inhalation and ingestion results obtained from the emission values of each plant.

The inhalation sections show the maximum and minimum values of the RI (Risk Index) and Individual Risk Excess acquired for all receptors. The IRE indices were calculated for both workers and residents. The following tables show the residents results because those have longer exposure than the workers.

The ingestion risk analysis was done only for the exposure at the residents' area. Therefore, the potential risk analysis excluded the receptors located at industrial zones.

4.1 POTENTIAL RISK ANALYSIS RESULTS: FACTORY OF LORCA

4.1.1 Inhalation exposure results

The following tables show the results of risks by inhalation, according to the emission values of each plant. The maximum and minimum values of RI (Risk Index) and Individual Risk Excess obtained for all the receptors of each substance are presented.

Results of the Risk Index (RI) lower than 1 mean that the exposure values obtained are below the acceptable thresholds; therefore those values do not represent a significant risk to develop an adverse effect to human health.

Table 4. Results of risk by inhalation exposure, obtained from the emissions values.

Inhalation exposure	Effects with threshold		Effects without threshold	
	RI		IRE Residents	
	Maximum	Minimum	Maximum	Minimum
NO_X	1.11E-02	1.54E-04	-	-
SO_2	3.03E-03	4.21E-05	-	-
HCl	6.62E-05	9.19E-07	-	-
HF	7.27E-06	1.01E-07	-	-
CO	4.06E-05	5.63E-07	-	-
PM tot	3.23E-04	7.50E-06	-	-
Dioxins and furans	3.39E-08	1.30E-09	-	-
Sb	1.86E-06	2.70E-08	-	-
As	8.66E-05	1.26E-06	3.68E-09	5.34E-11
Cd	2.33E-05	3.33E-07	3.59E-10	5.14E-12
Co	4.65E-06	6.75E-08	-	-
Cu	7.83E-07	1.14E-08	-	-
Cr III	4.13E-09	1.10E-10	-	-
Cr VI	5.78E-06	1.54E-07	9.92E-09	2.64E-10
Mn	8.60E-05	1.25E-06	-	-
Hg	1.85E-06	2.69E-08	-	-
Ni	1.86E-05	2.71E-07	2.73E-10	3.97E-12
Pb	3.71E-06	5.39E-08	9.53E-12	1.39E-13
REFERENCE VALUE	1		$1 \cdot 10^{-5}$	

In order to simplify the risk quantifying, Table 5 shows the risk index of each group of parameters compared which the threshold below wich there is a negligible human health risk.

For those effects related with substances without threshold, the Individual Risk Excess (IRE) represents the likelihood that an adverse effect to human health during the life time will appear. Table 6 shows the IRE values of each group of parameters compared with the excess risk considered as negligible risk.

Table 5. Risk index of each group of parameters and comparative with threshold (inhalation).

Pollutant	Risk Index
NO_x	Between 100 and 10 000 times lower than the threshold
SO_2	Between 1 000 and 100 000 times lower than the threshold
Gases: CO, HCl, HF	Between 100 000 and 10 000 000 times lower than the threshold
Particles	Between 10 000 and 1 000 000 times lower than the threshold
Dioxins and furans	Between 100 000 000 and 1 000 000 000 times lower than the threshold
Metals	Between 100 000 and 10 000 000 000 times lower than the threshold

Table 6. Individual Risk Excess for each group of parameters.

Pollutant	IRE value
As, Cr VI	Between 10 000 and 1 000 000 times lower than the likelihood established as negligible *
Cd, Pb, Ni	Between 100 000 and 100 000 000 times lower than the likelihood established as negligible *

* Note: Literature about toxicology usually established 1/100 000 as negligible risk on those effects without threshold.

Table 7 shows the results of the Risk Index obtained under the hypothesis that the plant had the same emission levels as those established at the permit. The real emissions are lower than these limits, leaving this hypothesis highly conservative.

In conclusion, even with the hypothesis that the emission levels are maintained in the long term at the limits established by the European and Spanish normative, there is a negligible risk by inhalation for any of the receptors.

4.1.2 Ingestion exposure results

Table 8 shows the results of risks by ingestion, according to the emission values of each plant. The maximum and minimum values of RI (Risk Index) and Individual Risk Excess for all receptors are shown.

Results of the Risk Index (RI) lower than 1 mean that the exposure values obtained are below the acceptable thresholds; therefore those values do not represent a significant risk to develop an adverse effect to human health.

Table 7. Results of the inhalation risk, obtained according to the hypothesis of limit emissions values.

Exposure by inhalation	Effects with threshold		Effects without threshold	
	RI		IRE Residents	
	Maximum	Minimum	Maximum	Minimum
NO_x	1.13E-02	1.57E-04	-	-
SO_2	1.39E-02	1.92E-04	-	-
HCl	2.80E-04	3.89E-06	-	-
HF	4.36E-05	6.06E-07	-	-
PM tot	5.65E-04	1.92E-05	-	-
Dioxins and furans	2.30E-05	8.86E-07	-	-
Sb	2.58E-05	3.74E-07	-	-
As	1.20E-03	1.75E-05	5.11E-08	7.41E-10
Cd	3.37E-04	1.29E-05	5.19E-9	2.00E-10
Co	6.45E-05	9.36E-07	-	-
Cu	1.10E-05	1.59E-07	-	-
Cr III	6.19E-08	2.38E-09	-	-
Cr VI	8.68E-05	3.34E-06	1.49E-07	5.72E-09
Mn	1.19E-03	1.73E-05	-	-
Hg	7.17E-05	1.04E-06	-	-
Ni	2.59E-04	3.76E-06	3.79E-09	5.50E-11
Pb	5.16E-05	7.48E-07	1.33E-10	1.92E-12
REFERENCE VALUE	1		$1 \cdot 10^{-5}$	

Table 8. Results of risk by ingestion exposure obtained from the emissions values.

Exposure by ingestion	Effects with threshold				Effects without threshold	
	RI Children		RI Adults		IRE Residents	
	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum
Dioxins and furans	2.51E-06	1.01E-07	7.06E-07	2.83E-08	-	-
Sb	1.67E-06	2.54E-08	3.33E-07	5.09E-09	-	-
As	1.19E-06	1.82E-08	2.24E-07	3.42E-09	4.33E-11	6.60E-13
Cd	2.67E-07	4.02E-09	5.87E-08	8.83E-10	-	-
Pb	1.50E-06	2.29E-08	1.77E-07	2.70E-09	2.30E-12	3.51E-14
Tl	5.38E-06	2.16E-07	6.88E-07	2.76E-08	-	-
V	4.81E-06	7.33E-08	5.39E-07	8.22E-09	-	-
REFERENCE VALUE	1				$1 \cdot 10^{-5}$	

In order to simplify the risk quantifying, two tables are presented below: the following table shows the risk index of each group of parameters compared with the threshold below with there is a negligible human health risk.

Table 9. Risk index of each group of parameters and comparative with threshold (ingestion).

Pollutant	Risk Index
Dioxins and furans	Between 1 000 000 and 10 000 000 times lower than the threshold
Metals	Between 1 000 000 and 1 000 000 000 times lower than the threshold

For those effects related with substances without threshold, the Individual Risk Excess (IRE) represents the likelihood that an adverse effect to human health during the life time will develop. The following table shows the IRE values of each group of parameters compared with the excess risk considered as negligible risk.

Table 10. Individual Risk Excess for each group of parameters.

Pollutant	IRE value
As	Between 1 000 000 and 100 000 000 times lower than the likelihood established as negligible *
Pb	Between 10 000 000 and 1 000 000 000 times lower than the likelihood established as negligible *

* Note: Literature about toxicology usually established 1/100 000 as negligible risk on those effects without threshold.

Table 11 shows the results of the Risk Index obtained with the hypothesis that the plant have the same emission levels as those established at the permit. The real emissions are lower than these limits, leaving this hypothesis highly conservative.

In conclusion, even with the hypothesis that the emission levels are maintained in the long term at the limits established by the European and Spanish normative, there is a negligible risk by ingestion for any of the receptors.

In addition, pollutants deposition that would involve an ingestion risk index of 1 (risk threshold) for people feeding on plants grown in this area, was calculated. The following table shows these values, named "dry deposition threshold" ($F_{threshold}$). These

Table 11. Results of the ingestion risk, obtained according to the hypothesis of limit emissions values.

Exposure by ingestion	Effects with threshold				Effects without threshold	
	RI Children		RI Adults		IRE Residents	
	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum
Dioxins and furans	9.49E-05	3.81E-06	2.67E-05	1.07E-06	-	-
Sb	2.32E-05	3.53E-07	4.63E-06	7.06E-08	-	-
As	1.66E-05	2.52E-07	3.12E-06	4.75E-08	6.01E-10	9.16E-12
Cd	4.11E-06	1.65E-07	9.03E-07	3.62E-08	-	-
Pb	2.09E-05	3.18E-07	2.46E-06	3.75E-08	3.20E-11	4.88E-13
Tl	5.21E-05	7.93E-07	6.66E-06	1.01E-07	-	-
V	6.68E-05	1.02E-06	7.49E-06	1.14E-07	-	-
REFERENCE VALUE	1				$1 \cdot 10^{-5}$	

Tabla 12. "Deposition threshold" and ratio between the maximum deposition and the "threshold deposition".

Receptors with the highest deposition rate	$F_{threshold}$ (µg/m²/s)*		Ratio $F/F_{threshold}$**	
	Adults	Children	Adults	Children
Dioxins and furans	3.75E-09	1.05E-09	7.12E-07	2.54E-06
Sb	1.25E-02	2.51E-03	3.86E-07	1.91E-06
As	1.78E-02	3.42E-03	2.70E-07	1.40E-06
Cd	1.32E-02	2.90E-03	6.50E-08	2.96E-07
Pb	1.31E-02	1.81E-03	2.61E-07	1.89E-06
Tl	3.06E-03	4.47E-04	9.89E-07	6.78E-06
V	1.05E-03	1.41E-04	8.19E-07	6.11E-06

* Dry deposition threshold (RI=1)
** Ratio between the dry deposition of the receptor with the highest related deposition and the dry deposition threshold.

are compared with the maximum deposition values obtained from the plant emissions in whole receptors (F).

The results of the $F/F_{threshold}$ ratio are well below the unity. This means that the pollutant deposition values from the plant are, at least, a million times under the deposition that would generate risk index by ingestion equal to the unit.

4.2 POTENTIAL RISK ANALYSIS RESULTS: FACTORY OF MONTCADA

4.2.1 Inhalation exposure results

The following table shows the results of risks by inhalation, according to the emission values of each plant. The maximum and minimum values of RI (Risk Index) and Individual Risk Excess for all receptors are shown.

Results of the Risk Index (RI) lower than 1 mean that the exposure values obtained are below the acceptable thresholds; therefore those values do not represent a significant risk to develop an adverse effect to human health.

Table 13. Results of risk by inhalation exposure, obtained from the emissions values.

Inhalation exposure	Effects with threshold		Effects without threshold	
	RI		IRE Residents	
	Maximum	Minimum	Maximum	Minimum
NO_X	2.19E-01	3.53E-02	-	-
SO_2	1.81E-02	2.93E-03	-	-
HCl	6.03E-05	9.74E-06	-	-
HF	1.98E-04	3.21E-05	-	-
CO	8.25E-04	1.33E-04	-	-
PM tot	5.48E-03	1.19E-03	-	-
Dioxins and furans	1.11E-06	2.41E-07	-	-
Sb	2.90E-05	4.65E-06	-	-
As	3.55E-03	5.70E-04	1.51E-07	2.42E-08
Cd	1.24E-02	1.99E-03	1.92E-07	3.08E-08
Co	2.39E-05	3.84E-06	-	-
Cu	3.42E-04	5.49E-05	-	-
Cr III	3.44E-06	5.53E-07	-	-
Cr VI	8.85E-04	1.42E-04	1.52E-06	2.44E-07
Mn	2.20E-02	3.54E-03	-	-
Hg	2.60E-04	4.14E-05	-	-
Ni	5.00E-03	8.03E-04	7.33E-08	1.18E-08
Pb	7.87E-04	1.71E-04	2.02E-09	4.39E-10
REFERENCE VALUE	1		$1 \cdot 10^{-5}$	

In order to simplify the risk quantifying, two tables are presented below: the following table shows the risk index of each group of parameters compared with the threshold below with there is a negligible human health risk.

Table 14. Risk index of each group of parameters and comparative with threshold (inhalation).

Pollutant	Risk Index
NO_x	Between 10 and 100 times lower than the threshold
SO_2	Between 100 and 1 000 times lower than the threshold
Gases: CO, HCl, HF	Between 10 000 and 1 000 000 times lower than the threshold I
Particles	Around a 1 000 times lower than the threshold
Dioxins and furans	Between 1 000 000 and 10 000 000 times lower than the threshold
Metals	Between 100 and 10 000 000 times lower than the threshold

For those effects related with substances without threshold, the Individual Risk Excess (IRE) represents the likelihood to develop an adverse effect to human health during the life time. The following table shows the IRE values of each group of parameters compared with the excess risk considered as negligible risk.

Table 15. Individual Risk Excess for each group of parameters.

Pollutant	IRE value
As, Cr VI	Between 10 and 1 000 times lower than the likelihood established as negligible *
Cd, Pb, Ni	Between 100 and 100 000 times lower than the likelihood established as negligible *

* Note: Literature about toxicology usually established 1/100 000 as negligible risk on those effects without threshold.

The following table shows the results of the Risk Index obtained with the hypothesis that the plant had the same emission levels as those established at the permit. The real emissions are lower than these limits, leaving this hypothesis highly conservative.

In conclusion, even with the hypothesis that the emission levels are maintained in the long term at the limits established by the European and Spanish normative, there is a negligible risk by inhalation for any of the receptors.

Table 16. Results of the inhalation risk, obtained according to the hypothesis of limit emissions values.

Inhalation exposure	Effects with threshold		Effects without threshold	
	RI		IRE Residents	
	Maximum	Minimum	Maximum	Minimum
NO_X	2.41E-01	3.89E-02	-	-
SO_2	3.02E-02	4.86E-03	-	-
HCl	6.08E-03	9.81E-04	-	-
HF	8.87E-04	1.43E-04	-	-
PM tot	1.63E-02	3.54E-03	-	-
Dioxins and furans	2.72E-05	5.89E-06	-	-
Sb	5.27E-05	8.63E-06	-	-
As	6.45E-03	1.06E-03	2.73E-07	4.48E-08
Cd	1.02E-02	1.67E-03	1.57E-07	2.58E-08
Co	4.34E-05	7.11E-06	-	-
Cu	6.22E-04	1.02E-04	-	-
Cr III	6.27E-06	1.03E-06	-	-
Cr VI	1.61E-03	2.64E-04	2.76E-06	4.52E-07
Mn	4.01E-02	6.56E-03	-	-
Hg	1.87E-03	3.04E-04	-	-
Ni	9.11E-03	1.49E-03	1.34E-07	2.19E-08
Pb	1.46E-03	3.16E-04	3.75E-09	8.13E-10
REFERENCE VALUE	1		$1 \cdot 10^{-5}$	

4.2.2 Ingestion exposure results

Table 17 shows the results of risks by ingestion, according to the emission values of each plant. The maximum and minimum values of RI (Risk Index) and Individual Risk Excess for all receptors are shown.

Results of the Risk Index (RI) lower than 1 mean that the exposure values obtained are below the acceptable thresholds; therefore those values do not represent a significant risk to develop an adverse effect to human health.

In order to simplify the risk quantifying, Table 18 shows the risk index of each group of parameters compared with the threshold below with there is a negligible human health risk.

Table 17. Results of risk by ingestion exposure obtained from the emissions values.

Inhalation exposure	Effects with threshold				Effects without threshold	
	RI Children		RI Adults		IRE Residents	
	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum
Dioxins and furans	4.86E-05	1.12E-05	1.37E-05	3.15E-06	-	-
Sb	9.48E-06	1.62E-06	2.11E-06	3.61E-07	-	-
As	2.03E-05	3.48E-06	4.62E-06	7.92E-07	8.91E-10	1.53E-10
Cd	4.72E-05	8.09E-06	1.08E-05	1.85E-06	-	-
Pb	9.87E-05	2.27E-05	1.20E-05	2.76E-06	1.56E-10	3.60E-11
Tl	5.16E-04	1.19E-04	8.53E-05	1.96E-05	-	-
V	1.32E-03	3.03E-04	1.52E-04	3.51E-05	-	-
REFERENCE VALUE	1				$1 \cdot 10^{-5}$	

Table 18. Risk index of each group of parameters and comparative with threshold (ingestion).

Pollutant	Risk Index
Dioxins and furans	Between 100 000 and 1 000 000 times lower than the threshold
Metals	Between 1 000 and 10 000 000 times lower than the threshold

For those effects related with substances without threshold, the Individual Risk Excess (IRE) represents the likelihood that an adverse effect to human health during the life time will appear. The following table shows the IRE values of each group of parameters compared with the excess risk considered as negligible risk.

Table 19. Individual Risk Excess for each group of parameters.

Pollutant	IER value
As	Around a 100 000 times lower than the likelihood established as negligible *
Pb	Between 100 000 and 1 000 000 times lower than the likelihood established as negligible *

* Note: Literature about toxicology usually established 1/100 000 as negligible risk on those effects without threshold.

The following table shows the results of the Risk Index obtained with the hypothesis that the plant had the same emission levels as those established at the permit. The real emissions are lower than these limits, leaving this hypothesis highly conservative.

In conclusion, even with the hypothesis that the emission levels are maintained in the long term at the limits established by the European and Spanish normative, there is a negligible risk by ingestion for any of the receptors.

Table 20. Results of the ingestion risk, obtained according to the hypothesis of limit emissions values.

Exposure by ingestion	Effects with threshold				Effects without threshold	
	RI Children		RI Adults		IRE Residents	
	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum
Dioxins and furans	1.19E-03	2.73E-04	3.34E-04	7.68E-05	-	-
Sb	1.73E-05	3.01E-06	3.85E-06	6.69E-07		
As	3.71E-05	6.45E-06	8.44E-06	1.47E-06	1.63E-09	2.83E-10
Cd	3.90E-05	6.78E-06	8.93E-06	1.55E-06	-	-
Pb	1.83E-04	4.21E-05	2.23E-05	5.12E-06	2.90E-10	6.66E-11
Tl	4.05E-04	9.30E-05	6.69E-05	1.54E-05	-	-
V	2.44E-03	5.62E-04	2.83E-04	6.50E-05	-	-
REFERENCE VALUE	1				$1 \cdot 10^{-5}$	

In addition, pollutants deposition that would involve an ingestion risk index of 1 (risk threshold) for people feeding on plants grown in this area, was calculated. The following table shows these values, named "dry deposition threshold" ($F_{threshold}$). These are compared with the maximum deposition values obtained from the plant emissions in whole receptors (F).

The results of the $F/F_{threshold}$ ratio are well below the unity. This means that the pollutant deposition values from the plant are, at least, a thousand times under the deposition that would generate risk index by ingestion equal to the unit.

Table 21. "Deposition threshold" and ratio between the maximum deposition and the "threshold deposition".

	$F_{threshold}$ (µg/m²/s)*		Ratio $F/F_{threshold}$**	
Receptors with the highest deposition rate	Adults	Childrens	Adults	Childrens
Dioxins and furans	3.75E-09	1.05E-09	1.38E-05	4.91E-05
Sb	2.00E-02	4.42E-03	2.36E-06	1.07E-05
As	2.38E-02	5.38E-03	5.19E-06	2.30E-05
Cd	2.44E-02	5.54E-03	1.18E-05	5.20E-05
Pb	2.62E-02	3.68E-03	1.75E-05	1.24E-04
Tl	4.50E-03	7.83E-04	1.09E-04	6.27E-04
V	2.10E-03	2.86E-04	2.28E-04	1.67E-03

* Dry deposition threshold (RI=1)
** Ratio between the dry deposition of the receptor with the highest related deposition and the dry deposition threshold.

4.3 POTENTIAL RISK ANALYSIS RESULTS: FACTORY OF VALLCARCA

4.3.1 Inhalation exposure results

The following table shows the results of risks by inhalation, according to the emission values of each plant. The maximum and minimum values of RI (Risk Index) and Individual Risk Excess for all receptors are shown.

Results of the Risk Index (RI) lower than 1 mean that the exposure values obtained are below the acceptable thresholds; therefore those values do not represent a significant risk to develop an adverse effect to human health.

Table 22. Results of risk by inhalation exposure, obtained from the emissions values.

Inhalation exposure	Effects with threshold		Effects without threshold	
	RI		IRE Residents	
	Maximum	Minimum	Maximum	Minimum
NO_X	6.84E-02	1.12E-02	-	-
SO_2	1.84E-02	2.98E-03	-	-
HCl	4.26E-05	6.95E-06	-	-
HF	6.17E-05	9.99E-06	-	-
CO	1.23E-03	1.99E-04	-	-
PM tot	7.15E-04	9.92E-05	-	-
Dioxins and furans	1.58E-06	2.16E-07	-	-
Sb	1.55E-05	2.37E-06	-	-
As	7.23E-04	1.11E-04	3.07E-08	4.35E-09
Cd	1.59E-03	2.41E-04	2.45E-08	3.36E-09
Co	4.89E-05	7.49E-06	-	-
Cu	5.38E-05	8.17E-06	-	-
Cr III	2.20E-07	3.35E-08	-	-
Cr VI	5.65E-05	8.60E-06	9.68E-08	1.35E-08
Mn	3.57E-04	5.42E-05	-	-
Hg	7.65E-05	1.18E-05	-	-
Ni	2.94E-04	4.47E-05	4.31E-09	5.99E-10
Pb	2.89E-05	4.07E-06	7.43E-11	9.35E-12
REFERENCE VALUE	1		1·10-5	

Table 23. Risk index of each group of parameters and comparative with threshold (inhalation).

Pollutant	Risk Index
NO_x	Around a 100 times lower than the threshold
SO_2	Between 100 and 1 000 times lower than the threshold
Gases: CO, HCl, HF	Between 1 000 and 1 000 000 times lower than the threshold
Particles	Between 10 000 and 100 000 times lower than the threshold
Dioxins and furans	Between 1 000 000 and 10 000 000 times lower than the threshold
Metals	Between 1 000 and 100 000 000 times lower than the threshold

Table 24. Individual Risk Excess for each group of parameters.

Pollutant	IRE value
As, Cr VI	Between 1 000 and 10 000 times lower than the likelihood established as negligible *
Cd, Pb, Ni	Between 1 000 and 10 000 000 times lower than the likelihood established as negligible *

* Note: Literature about toxicology usually established 1/100 000 as negligible risk on those effects without threshold.

Table 25a. Results of the inhalation risk, obtained according to the hypothesis of limit emissions values.

Inhalation exposure	Effects with threshold		Effects without threshold	
	RI		IER Residents	
	Maximum	Minimum	Maximum	Minimum
NO_x	7.14E-02	1.18E-02	-	-
SO_2	1.07E-01	1.78E-02	-	-
HCl	1.76E-03	2.92E-04	-	-
HF	2.80E-04	4.64E-05	-	-
PM tot	8.22E-03	9.97E-04	-	-
Dioxins and furans	1.37E-05	1.66E-06	-	-
Sb	2.45E-04	3.59E-05	-	-
As	1.14E-02	1.68E-03	4.85E-07	7.11E-08
Cd	9.82E-03	1.52E-03	1.52E-07	2.34E-08
Co	6.91E-04	1.01E-04	-	-
Cu	2.47E-04	3.63E-05	-	-
Cr III	2.04E-06	3.00E-07	-	-
Cr VI	5.26E-04	7.72E-05	9.02E-07	1.32E-07
Mn	2.11E-03	3.09E-04	-	-
REFERENCE VALUE	1		$1 \cdot 10^{-5}$	

Table 25b. Results of the inhalation risk, obtained according to the hypothesis of limit emissions values.

Inhalation exposure	Effects with threshold		Effects without threshold	
	RI		IER Residents	
	Maximum	Minimum	Maximum	Minimum
Hg	5.86E-04	8.60E-05	-	-
Ni	2.02E-03	2.96E-04	2.96E-08	4.34E-09
Pb	4.21E-04	5.54E-05	1.08E-09	1.42E-10
REFERENCE VALUE	1		$1 \cdot 10^{-5}$	

In order to simplify the risk quantifying, Table 23 shows the risk index of each group of parameters compared with the threshold below with there is a negligible human health risk.

For those effects related with substances without threshold, the Individual Risk Excess (IRE) represents the likelihood that an adverse effect to human health during the life time will appear. Table 24 shows the IRE values of each group of parameters compared with the excess risk considered as negligible risk.

Table 25 shows the results of the Risk Index obtained with the hypothesis that the plant had the same emission levels as those established at the permit. The real emissions are lower than these limits, leaving this hypothesis highly conservative.

In conclusion, even with the hypothesis that the emission levels are maintained in the long term at the limits established by the European and Spanish normative, there is a negligible risk by inhalation for any of the receptors.

4.3.2 Ingestion exposure results

The following tables show the results of risks by ingestion, according to the emission values of each plant. The maximum and minimum values of RI (Risk Index) and Individual Risk Excess for all receptors are shown.

Table 26. Results of risk by ingestion exposure obtained from the emissions values.

Exposure by ingestion	Effects with threshold				Effects without threshold	
	RI Children		RI Adults		IRE Residents	
	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum
Dioxins and furans	9.33E-04	7.36E-05	2.62E-04	2.07E-05	-	-
Sb	1.03E-05	1.24E-06	2.05E-06	2.47E-07	-	-
As	7.33E-06	8.85E-07	1.38E-06	1.66E-07	2.65E-10	3.20E-11
Cd	1.35E-05	1.60E-06	2.97E-06	3.52E-07	-	-
Pb	8.80E-06	9.35E-07	1.04E-06	1.10E-07	1.35E-11	1.44E-12
Tl	2.65E-05	3.20E-06	3.38E-06	4.09E-07	-	-
V	5.91E-04	6.22E-05	6.63E-05	6.97E-06	-	-
REFERENCE VALUE	1				$1 \cdot 10^{-5}$	

Results of the Risk Index (RI) lower than 1 mean that the exposure values obtained are below the acceptable thresholds; therefore those values do not represent a significant risk to develop an adverse effect to human health.

In order to simplify the risk quantifying, two tables are presented below: the following table shows the risk index of each group of parameters compared with the threshold below with there is a negligible human health risk.

Table 27. Risk index of each group of parameters and comparative with threshold (ingestion).

Pollutant	Risk Index
Dioxins and furans	Between 10 000 and 100 000 times lower than the threshold
Metals	Between 10 000 and 10 000 000 times lower than the threshold

For those effects related with substances without threshold, the Individual Risk Excess (IRE) represents the likelihood that an adverse effect to human health during the life time will appear. The following table shows the IRE values of each group of parameters compared with the excess risk considered as negligible risk.

Table 29 shows the results of the Risk Index obtained with the hypothesis that the plant had the same emission levels as those established at the permit.

Table 28. Individual Risk Excess for each group of parameters.

Pollutant	IRE value
As	Between 100 000 and 1 000 000 times lower than the likelihood established as negligible *
Pb	Between 1 000 000 and 10 000 000 times lower than the likelihood established as negligible *

* Note: Literature about toxicology usually established 1/100 000 as negligible risk on those effects without threshold.

The real emissions are lower than these limits, leaving this hypothesis highly conservative.

Table 29. Results of the ingestion risk, obtained according to the hypothesis of limit emissions values.

Ingestion exposure	Effects with threshold				Effects without threshold	
	RI Children		RI Adults		IRE Residents	
	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum
Dioxins and furans	8.02E-03	6.43E-04	2.26E-03	1.81E-04	-	-
Sb	1.62E-04	1.99E-05	3.23E-05	3.98E-06	-	-
As	1.16E-04	1.42E-05	2.17E-05	2.67E-06	4.19E-09	5.15E-10
Cd	8.28E-05	1.05E-05	1.82E-05	2.30E-06	-	-
Pb	1.28E-04	1.37E-05	1.51E-05	1.62E-06	1.96E-10	2.11E-11
Tl	2.74E-04	3.40E-05	3.50E-05	4.34E-06	-	-
V	5.56E-03	5.86E-04	6.23E-04	6.56E-05	-	-
REFERENCE VALUE	1				$1 \cdot 10^{-5}$	

In conclusion, even with the hypothesis that the emission levels are maintained in the long term at the limits established by the European and Spanish normative, there is a negligible risk by ingestion for any of the receptors.

In addition, pollutants deposition that would involve an ingestion risk index of 1 (risk threshold) for people feeding on plants grown in this area, was calculated. The following table shows these values, named "dry deposition threshold" ($F_{threshold}$). These are compared with the maximum deposition values obtained from the plant emissions in whole receptors (F).

Table 30. "Deposition threshold" and ratio between the maximum deposition and the "threshold deposition".

Receptors with the highest deposition rate	$F_{threshold}$ (µg/m²/s)*		Ratio $F/F_{threshold}$**	
	Adults	Children	Adults	Children
Dioxins and furans	3.75E-09	1.05E-09	6.33E-04	2.26E-03
Sb	1.24E-02	2.50E-03	5.54E-06	2.75E-05
As	1.78E-02	3.40E-03	3.86E-06	2.01E-05
Cd	1.31E-02	2.88E-03	7.18E-06	3.28E-05
Pb	1.30E-02	1.80E-03	3.62E-06	2.62E-05
Tl	3.05E-03	4.43E-04	1.13E-05	7.76E-05
V	1.04E-03	1.40E-04	2.21E-04	1.65E-03

* Dry deposition threshold (RI=1)
** Ratio between the dry deposition of the receptor with the highest related deposition and the dry deposition threshold.

The results of the $F/F_{threshold}$ ratio are well below the unity. This means that the pollutant deposition values from the plant are, at least, a thousand times under the deposition that would generate risk index by ingestion equal to the unit.

4.4 POTENTIAL RISK ANALYSIS RESULTS: FACTORY OF CASTILLEJO

4.4.1 Inhalation exposure results

The following table shows the results of risks by inhalation, according to the emission values of each plant. The maximum and minimum values of RI (Risk Index) and Individual Risk Excess for all receptors are shown.

Table 31a. Results of risk by inhalation exposure, obtained from the emissions values.

Inhalation exposure	Effects with threshold		Effects without threshold	
	RI		IRE Residents	
	Maximum	Minimum	Maximum	Minimum
NO_x	6.07E-02	8.58E-04	-	-
SO_2	1.75E-04	2.49E-06	-	-
HCl	9.23E-04	1.32E-05	-	-
HF	3.36E-05	4.74E-07	-	-
CO	1.11E-04	1.55E-06	-	-
REFERENCE VALUE	1		$1 \cdot 10^{-5}$	

Table 31b. Results of risk by inhalation exposure, obtained from the emissions values.

Inhalation exposure	Effects with threshold		Effects without threshold	
	RI		IRE Residents	
	Maximum	Minimum	Maximum	Minimum
PM tot	1.72E-03	2.24E-05	-	-
Dioxins and furans	3.88E-07	5.75E-09	-	-
Sn	8.36E-09	1.25E-10	-	-
As	7.94E-04	1.18E-05	3.37E-08	5.02E-10
Cd	9.64E-04	1.42E-05	1.49E-08	2.19E-10
Zn	6.79E-08	1.01E-09	-	-
Cu	8.01E-06	1.17E-07	-	-
Cr III	2.04E-07	3.05E-09	-	-
Cr VI	5.22E-05	7.82E-07	8.96E-08	1.34E-09
Mn	9.91E-04	1.46E-05	-	-
Hg	4.19E-05	6.27E-07	-	-
Ni	2.01E-04	2.99E-06	2.95E-09	4.38E-11
Pb	2.14E-04	3.23E-06	5.51E-10	8.30E-12
REFERENCE VALUE	1		$1 \cdot 10^{-5}$	

Results of the Risk Index (RI) lower than 1 mean that the exposure values obtained are below the acceptable thresholds; therefore those values do not represent a significant risk to develop an adverse effect to human health.

In order to simplify the risk quantifying, two tables are presented below: Table 32 shows the risk index of each group of parameters compared with the threshold below with there is a negligible human health risk.

For those effects related with substances without threshold, the Individual Risk Excess (IRE) represents the likelihood that an adverse effect to human health during the life time will appear. Table 33 shows the IRE values of each group of parameters compared with the excess risk considered as negligible risk.

Table 34 shows the results of the Risk Index obtained with the hypothesis that the plant had the same emission levels as those established at the permit.

Table 32. Risk index of each group of parameters and comparative with threshold (inhalation).

Pollutant	Risk Index
NO_X	Between 100 and 10 000 times lower than the threshold
SO_2	Between 10 000 and 1 000 000 times lower than the threshold
Gases: CO, HCl, HF	Between 10 000 and 10 000 000 times lower than the threshold
Particles	Between 1 000 and 100 000 times lower than the threshold
Dioxins and furans	Between 10 000 000 and 1 000 000 000 times lower than the threshold
Metals	Between 10 000 and 1 000 000 000 times lower than the threshold

Table 33. Individual Risk Excess for each group of parameters.

Pollutant	IRE value
As, Cr VI	Between 1 000 and 100 000 times lower than the likelihood established as negligible *
Cd, Pb, Ni	Between 1 000 and 10 000 000 times lower than the likelihood established as negligible *

* Note: Literature about toxicology usually established 1/100 000 as negligible risk on those effects without threshold.

Table 34a. Results of the inhalation risk, obtained according to the hypothesis of limit emissions values.

Exposure by inhalation	Effects with threshold		Effects without threshold	
	RI		IRE Residents	
	Maximum	Minimum	Maximum	Minimum
NO_X	1.12E-01	1.59E-03	-	-
SO_2	5.61E-03	7.98E-05	-	-
HCl	2.81E-03	3.99E-05	-	-
HF	4.01E-04	5.69E-06	-	-
CO	3.74E-04	5.60E-06	-	-
PM tot	7.72E-03	1.01E-04	-	-
Dioxins and furans	7.79E-06	1.17E-07	-	-
Sb	2.22E-03	3.33E-05	-	-
As	7.15E-03	1.07E-04	3.03E-07	4.55E-09
Cd	1.56E-02	2.33E-04	2.40E-07	3.60E-09
Co	3.11E-02	4.66E-04	-	-
Cu	1.36E-03	2.07E-05	-	-
REFERENCE VALUE	1		$1 \cdot 10^{-5}$	

Table 34b. Results of the inhalation risk, obtained according to the hypothesis of limit emissions values.

Exposure by inhalation	Effects with threshold		Effects without threshold	
	RI		IRE Residents	
	Maximum	Minimum	Maximum	Minimum
Cr III	1.90E-06	2.86E-08	-	-
Cr VI	4.89E-04	7.36E-06	8.38E-07	1.26E-08
Mn	7.67E-03	1.14E-04	-	-
Hg	1.04E-03	1.55E-05	-	-
Ni	1.73E-03	2.59E-05	2.54E-08	3.80E-10
Pb	2.18E-03	3.30E-05	5.60E-09	8.48E-11
Zn	6.13E-07	9.20E-09	-	-
Sn	8.16E-08	1.23E-09	-	-
REFERENCE VALUE	1		$1 \cdot 10^{-5}$	

The real emissions are lower than these limits, leaving this hypothesis highly conservative.

In conclusion, even with the hypothesis that the emission levels are maintained in the long term at the limits established by the European and Spanish normative, there is a negligible risk by inhalation for any of the receptors.

4.4.2 Ingestion exposure results

Table 35 shows the results of risks by ingestion, according to the emission values of each plant. The maximum and minimum values of RI (Risk Index) and Individual Risk Excess for all receptors are shown.

Results of the Risk Index (RI) lower than 1 mean that the exposure values obtained are below the acceptable thresholds; therefore those values do not represent a significant risk to develop an adverse effect to human health.

In order to simplify the risk quantifying, Table 36 shows the risk index of each group of parameters compared with the threshold below with there is a negligible human health risk.

Table 35. Results of risk by ingestion exposure obtained from the emissions values.

Ingestion Exposure	Effects with threshold				Effects without threshold	
	RI Children		RI Adults		IRE Residents	
	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum
Dioxins and furans	1.76E-05	3.53E-07	4.95E-06	9.94E-08	-	-
Sn	3.25E-07	6.56E-09	9.20E-08	1.85E-09	-	-
As	5.21E-06	1.05E-07	1.13E-06	2.27E-08	2.17E-10	4.38E-12
Cd	4.49E-06	9.00E-08	1.01E-06	2.03E-08	-	-
Pb	3.37E-05	6.80E-07	4.06E-06	8.20E-08	5.28E-11	1.07E-12
Tl	2.28E-05	4.58E-07	3.52E-06	7.05E-08	-	-
Zn	1.94E-06	3.91E-08	5.55E-07	1.12E-08	-	-
REFERENCE VALUE	1				$1 \cdot 10^{-5}$	

Table 36. Risk index of each group of parameters and comparative with threshold (ingestion).

Pollutant	Risk Index
Dioxins and furans	Between 100 000 and 10 000 000 times lower than the threshold
Metals	Between 100 000 and 1 000 000 000 times lower than the threshold

For those effects related with substances without threshold, the Individual Risk Excess (IRE) represents the likelihood that an adverse effect to human health during the life time will appear. The following table shows the IRE values of each group of parameters compared with the excess risk considered as negligible risk.

Table 37. Individual Risk Excess for each group of parameters.

Pollutant	IRE value
As	Between 100 000 and 10 000 000 times lower than the likelihood established as negligible *
Pb	Between 1 000 000 and 10 000 000 times lower than the likelihood established as negligible *

* Note: Literature about toxicology usually established 1/100 000 as negligible risk on those effects without threshold.

The following table shows the results of the Risk Index obtained with the hypothesis that the plant had the same emission levels as those established at the permit. The real emissions are lower than these limits, leaving this hypothesis highly conservative.

Table 38. Results of the ingestion risk, obtained according to the hypothesis of limit emissions values.

Ingestion exposure	Effects with threshold				Effects without threshold	
	RI Children		RI Adults		IRE Residents	
	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum
Dioxins and furans	3.53E-04	7.12E-06	9.94E-05	2.00E-06	-	-
Sb	8.67E-04	1.75E-05	1.87E-04	3.76E-06	-	-
As	4.69E-05	9.46E-07	1.02E-05	2.05E-07	1.96E-09	3.95E-11
Cd	7.27E-05	1.46E-06	1.64E-05	3.31E-07	-	-
Pb	3.43E-04	6.92E-06	4.13E-05	8.34E-07	5.37E-10	1.09E-11
Tl	4.50E-04	9.07E-06	6.94E-05	1.40E-06	-	-
V	1.25E-02	2.52E-04	1.43E-03	2.88E-05	-	-
Sn	3.18E-06	6.42E-08	8.99E-07	1.82E-08	-	-
Zn	1.75E-05	3.54E-07	5.01E-06	1.01E-07	-	-
REFERENCE VALUE	1				$1 \cdot 10^{-5}$	

In conclusion, even with the hypothesis that the emission levels are maintained in the long term at the limits established by the European and Spanish normative, there is a negligible risk by ingestion for any of the receptors.

In addition, pollutants deposition that would involve an ingestion risk index of 1 (risk threshold) for people feeding on plants grown in this area, was calculated. The following table shows

Table 39. "Deposition threshold" and ratio between the maximum deposition and the "threshold deposition".

Receptors with the highest deposition rate	$F_{threshold}$ (µg/m²/s)*		Ratio $F/F_{threshold}$**	
	Adults	Children	Adults	Children
Dioxins and furans	3.78E-09	1.06E-09	4.95E-06	1.76E-05
Sb	2.01E-02	4.34E-03	-	-
As	2.55E-02	5.51E-03	1.13E-06	3.08E-06
Cd	2.29E-02	5.17E-03	1.01E-06	2.74E-06
Pb	3.19E-02	3.84E-03	4.06E-06	1.95E-05
Tl	5.42E-03	8.35E-04	3.52E-06	1.39E-05
V	2.63E-03	3.01E-04	-	-
Sn	7.68E-01	2.17E-01	9.20E-08	3.25E-07
Zn	1.55E-01	4.43E-02	5.55E-07	1.94E-06

* Dry deposition threshold (RI=1)
** Ratio between the dry deposition of the receptor with the highest related deposition and the dry deposition threshold.

these values, named "dry deposition threshold" ($F_{threshold}$). These are compared with the maximum deposition values obtained from the plant emissions in whole receptors (F).

The results of the $F/F_{threshold}$ ratio are well below the unity. This means that the pollutant deposition values from the plant are, at least, a thousand times under the deposition that would generate risk index by ingestion equal to the unit.

Chapter 5 Conclusions

This study has evaluated the potential health risks, both by inhalation and ingestion, related to pollutants emitted by four cement plants, which represent distinct characteristics of the Spanish cement industry, such as location (urban and rural), used fuel (fossil fuel or alternative), emissions, relief and meteorological conditions. The studied emission parameters are those established by the Integrated Environmental Permit (IEP) according to the according to the Spanish and European law on Integrated Pollution Prevention and Control, waste incineration and co-incineration.

After analyzing the risk indices related to the receptors who live close to the cement plants, focusing on the exposure by inhalation and ingestion of the soil and fruit and vegetables growth around the studied area, the results are overwhelming clear that there is no significant health risk to any of the receptors.

The result shows that both the Risk Indices (RI) and the Individual Risk Excess (IRE) calculated are lower than the risk thresholds for every parameter and for every receptor:

- **Nitrogen oxide (NOx) and sulphur dioxide (SO_2):** Inhalation risk evaluated as negligible. The air concentrations derived from the cement plant emissions are below the air quality standards established in the normative according to the recommendations of the World Health Organization and other organisms.

- **Particles:** Inhalation risk evaluated as negligible. The air concentrations derived from the cement plant emissions are between a thousand and a million times below the air quality standards established in the normative according the recommendations of the World Health Organization and other organisms.

- **Carbon monoxide (CO), hydrochloric acid (HCl) and hydrofluoric acid (HF):** Inhalation risk evaluated as negligible. The air concentrations derived from the cement plant emissions are between a thousand and ten million times below the threshold recommended by several environmental agencies.

- **Dioxins and furans:** The results show as negligible the risk of inhalation and ingestion of these substances. The exposure values for people living around the

cement plants are between ten thousand and ten million times bellow the acceptable exposure thresholds.

- **Metals:** For these substances results have revealed as negligible risks of inhalation and ingestion. The risk indices obtained from the exposure values for people living around the cement plants are between a hundred and a thousand million times bellow the risk thresholds defined as acceptable.

The four cement plants show the following results:

- For substances with an established threshold value, the calculated concentrations are clearly below the corresponding TRV index (risk indices significantly lower than 1) for every receptor.

- For substances without threshold value, the Individual Risk Excess (IRE) indices are very lower than the reference considered value (1 / 100 000) for all the receptors.

- The values of the pollutants deposit on the ground are between a thousand and ten million times below the maximum dry deposit related to an acceptable risk value.

- These conclusions are valid both for the assessment done with the two defined scenarios: the plant emission values and the limit emissions values. The analysis done with the latter (limit emissions values) shows that the results obtained are higher than those with the first hypothesis, but are still much lower than the risk thresholds.

- The calculated risk indices have similar range of values both for plants that use petroleum coke fuel and those that use alternative fuels. Hence, the kind of fuel does not present a significant influence in the calculated risks indices.

Therefore, it can conclude that no potential health risk has been identified to any of the receptors in the assessed scenarios.

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