NANOTOXICOLOGY AND ENGINEERED NANOPARTICLE RISK ASSESSMENT
Industrial Hygiene

Engineered Nanoparticles (ENP) are increasingly produced for use in a wide range of industrial and consumer products. Yet it is known that exposure to some types of particles can cause severe health effects. Therefore it is essential to ascertain whether exposure to ENP can lead to possible health risks for workers and consumers. An approach for the Risk Assessment of ENP (ENPRA) is suggested. The specific objective would be to implement a risk assessment procedure for ENP using a Weight-of-Evidence approach. But for reaching this, a series of previous steps should be taken. First, it is necessary to obtain a bank of referential ENP with contrasting physico-chemical characteristics and characterize them with precision. Second, it would be fundamental to obtain knowledge about the toxic effects of ENP on different (pulmonary, hepatic, renal, cardiovascular and developmental) target systems using in vitro animal/human models. A variety of endpoints should be used for this approach. These in vitro findings should be validated with a small set of carefully chosen in vivo animal experiments. After that, mathematical models should be constructed to extrapolate the exposure-dose-response relationship from in vitro to in vivo and to humans, and the key ENP characteristics driving the adverse effects should be identified by means of QSAR like models. A last step, but not least important, is the dissemination of all these findings to potential stakeholders.

By: Lang Tran. Institute of Occupational Medicine, Research Avenue North, Edinburgh, EH14 4AP, UK. email: lang.tran@iom-world.org
Jose Maria Navas Antón. Dpt. of Environment Director, National Institute for Agricultural and food Research and Technology (INIA). Ctra de la Coruna 7,5. 28949 Madrid email: jmnavas@inia.es

Nanotechnology is one of the key industries in Europe[1]. The estimated economic impact of nanoparticles in industrial, consumer, and medical products will be US$ 292 billion by 2010 and US $1 trillion by 2015. The prosperity of our continent depends on the safe and sustainable development of this emerging technology[2]. Every new technology brings with it new risks and for nanotechnology, the potential health risks to workers and consumers are paramount. They can arise from exposure to nanomaterials either at work or through consumer products. These risks, if not assessed and managed properly, can prevent economic growth and deprive us of a much needed competitive edge, but more importantly could have grave potential consequences for human and environmental health[2;3].
Being aware of the health issues concerning engineered nanomaterials, in 2006, we have written an article, published in Nature[4], outlining the grand challenges for the safe handling of nanotechnology. It is clear that the production of safe nanomaterials is essential to establish and sustain the confidence of end users. This confidence is the ultimate guarantor for nanotechnology growth.

It is therefore essential to develop an effective approach for improving the assessment and management of potential health risks from exposure to ENP[5]. This is the aim of this article.

**Risk Assessment of ENP**

Traditionally, risk assessment would require elements of exposure and hazard characterisation. The main components of a risk assessment are: Hazard Identification; Dose-Response Assessment; Exposure Assessment; Risk Assessment and Management[6]. The same approach can be used as the starting point for a risk assessment of ENP. A summary of the state of the art for these components is given below:

**Hazard Identification**

One of the essential steps in any risk assessment process is to identify the associated hazard. If hazard could be defined as the potential to cause harmful effects, risk is the likelihood of this harm.

Hazard identification results highly difficult because the possible pathogenic mechanisms induced by particle exposure are very complex, depending on the route of exposure, dose, host response, susceptibility, and the specific physico-chemical properties of the individual particles (see e.g. review by Hoet et al.[7]). The primary nanoparticle exposure can be to the lungs, skin or gut but translocation to other target organs raises the possibility that different mechanisms of toxicity, dependent on the target organ, can operate. For example, redox conditions vary from highly oxidizing e.g., at the skin or in the lung to highly reducing in e.g., the intestine or interstitial sites, respectively; this could have an important impact on oxidative stress-driven mechanisms. Thus, for a proper assessment of ENP hazard, it is necessary to focus on all the body systems that are potential targets for ENP.

The current knowledge about the potential hazard of ENP to the main target systems is summarised below:

We are now going to look at the various types of explosions:

- **Lung.** Free radical or oxidative activity of ENP has been found to be a predominant factor in ability to cause lung inflammation[8; 9] and a similar mechanism is known to operate in the pulmonary genotoxicity of larger particles [10]. Additionally, there is likely to be a significant difference in the potential extent and mechanism of toxicity of ENP that differ in their solubility in the biological and environmental conditions they may encounter. ENP characteristics, such as surface area and surface reactivity, were demonstrated to be the driving metrics for generating oxidative stress leading to lung inflammation[11]. Since the lung is a major portal of entry for ENP to the body, there is a need to understand the mechanisms relating ENP physico-chemical characteristics to the pulmonary defence
system and adverse effects for a better risk assessment of lung exposure to ENP.

- **Cardio-vascular system.** Statistically significant associations between particulate air pollution and ischemic heart disease, arrhythmia, and heart failure have been reported and in animal studies exposure to ambient air particles increases peripheral thrombosis and atherosclerotic lesion formation[12]. This might be caused by particles entering the circulation or from inflammation /oxidative stress signals emanating from the site of deposition e.g. the lungs. Much less is known about the impact of manufactured ENP on the cardio-vascular system. However, the physico-chemical properties of the particulate surface have been shown to play an important role in the adverse effects in systemic circulation following lung administration[13]. The exact nature of the toxicity or ‘effective dose’ delivered by particles in lung or the circulation is unknown. It could however be via lung-derived mediators or the ability of the ENP to directly stimulate platelet aggregation/activation or to affect the endothelium in ways that favour atherosclerotic plaque destabilisation and thrombus formation. Oxidative stress could certainly be important in all of these effects. Clearly, for effective risk assessment of ENP effects in the cardio-vascular system there is a need for a better understanding of the mechanisms behind the ENP induced adverse effects.

- **Liver.** For blood borne particles the phagocytic Kupffer cells remain a key clearance system with subsequent potential for accumulation of dose in the liver. The Kupffer cells are macrophage-like cells and macrophages are known to be affected by oxidative stress from ENP to produce inflammatory mediators such as TNFα[14]. The liver is sensitive to oxidative stress and rat liver cells treated with various ENP were reported to undergo oxidative stress and injury[15]. The consequences of ENP injury to the liver could be inflammation, or alterations in the hepatic production of clotting factors that could contribute to systemic thrombosis[16]. Nothing is known of the role of particle size and chemistry on liver effects. The adverse health effects have not been related to ENP characteristics and the mechanisms behind liver toxicity is not fully understood.

- **Kidneys.** The kidney receives 20% of the cardiac output. Therefore, once particles enter the blood, the kidney potentially receives a high dose compared to other organs. The kidney eliminates many toxicants by plasma filtration. The potential consequences of exposure of the kidney, requires investigation of the potential urinary excretion, kidney accumulation and toxicity. Certainly nanoparticles injected into the blood can be filtered in the kidneys and excreted, as shown in one study with derivatised carbon nanotubes[17]. Also a gender-specific accumulation of silver ENP was observed in kidneys from rats in a 28 day oral toxicity study[18]. Nothing is known regarding the role of particle characteristics such as size or surface in any effects on the kidney. However, given the well recognised importance of charge in glomerular filtration, the zeta potential of the ENP may be important.

- **Developmental effects.** The apparent proclivity of ENP to translocate from their portal of entry means that there is at least potential for developing tissue to be affected. This is a concern for children, who are undergoing a spectrum of developmental changes as well as for embryos and foetuses. Entry of ENP into the blood means that they are likely to flow through the placenta where the foetal circulation comes close to the maternal circulation, although
there is no actual contact or mixing of blood. However the placenta is an organ designed to transfer molecules from the mother to the embryo/foetus so there is potential for transfer of very small particles. Adverse effects to the developmental system are of primary concern.

**Currently, there is a knowledge gap in this field and data showing the interaction of ENP and its characteristics with embryonic cells will help in assessing the risk of ENP exposure to the developmental systems.**

The current quantitative support tools for investigation are specified in the OECD guidelines and the new EU regulatory framework REACH (Registration, Evaluation and Authorisation of Chemicals [http://ec.europa.eu/environment/chemicals/reach/reach_intro.htm](http://ec.europa.eu/environment/chemicals/reach/reach_intro.htm)). They are (i) standard regulatory toxicology tests; (ii) Quantitative-Structure-Activity-Relationship (QSAR) and (iii) Physiologically-Based-Pharmaco-Kinetics model (PBPK). The state-of-the-art knowledge for these tools are summarised below:

- **Regulatory toxicology tests** The OECD guidelines for the toxicology testing of chemicals has been implemented for many toxicology endpoints considering soluble chemicals. The OECD is currently considering alternative testing strategy for nanomaterials taking into account the different physical-chemical properties that they present with respect to the bulk material, that leads to considering different variables than just chemical concentration to explain the effects observed.

- **Quantitative Structure Activity Relationship (QSAR)** The underlying assumption for QSAR is that similar chemical structures exhibit similar biological activities regarding both the biological mechanism and the quantitative response. The aim of a QSAR model is to gain an understanding of which properties have a large influence on the biological activity and to be able to predict the activity of previously untested structures/compounds. The use of toxicity-based QSAR is a well-established approach for predicting the toxicity of chemicals for a wide variety of endpoints. The growing importance of in silico methods such as QSAR for providing information about toxicity is reflected in a number of regulatory frameworks (e.g. REACH) where these approaches are considered acceptable methods (under certain conditions) for filling in knowledge gaps of chemical information for untested chemicals. Very few studies have attempted to develop QSAR for ENP and toxicity-based QSAR for ENP are almost non-existent. The increasing production of novel formulations of ENP by the nanotechnology industry and their increasing industrial usage poses an immediate problem for hazard and risk assessment, as many of them remain untested and thus QSAR, and in silico tools in general, are highly desirable methods to predict their toxicity.

- **Physiologically-Based-Pharmaco-Kinetics (PBPK) model** As acknowledged by the SCENIHR committee there is currently no established PBPK model for the distribution of nanoparticles in the body ([http://ec.europa.eu/health/ph_risk/committees/04_scenihr/scenihr_cons_04_en.htm](http://ec.europa.eu/health/ph_risk/committees/04_scenihr/scenihr_cons_04_en.htm)). ENP are quite larger than
molecules and the standard PBPK model transport equations need to be re-examined to assess their validity for particles. A PBPK model has been developed at NIOSH (http://www.cdc.gov/niosh/topics/nanotech/strat_planAPPXe.html). A nanoparticle PBPK/PD model is essential for describing the ENP exposure-dose-response relationship and the extrapolation of this relationship between species[19], as such, it plays a key role in the risk assessment for ENP.

Extrapolation obtained in vitro to in vivo models can be a very useful tool. Information on the toxicity of chemicals can be obtained faster, easier and at lower cost in in vitro experiments compared to in vivo experiments. However, a major issue always remains how to translate the results of in vitro experiments into the in vivo situation. For a quantitative in vitro-in vivo comparison dose-response modeling is required[20]. An example of such a comparison is the study by Slob et al.[21], where in vitro dose-responses were correlated with in vivo dose-responses for 20 different embryotoxic compounds (inducing toxicity via different mechanisms). As this study shows, this methodology is effective for the purpose of assessing the predictive power of in vitro results. Dose-response modelling is not only required for quantitative comparisons of in vitro to in vivo studies, but also to evaluate and compare different in vitro studies to each other. This also holds for evaluating and comparing in vivo studies to each other (see e.g., [22; 23]).

**Dose-Response Assessment**

The biological effects of a number of particle types in a non-nano size range (e.g. silica, asbestos, particulate air pollution (PM10)) was studied in animals and humans, and these have generally focused on those entering the body via the lungs. While some particles are found to be harmless at the doses to which humans are potentially exposed (e.g. TiO2)[24] other particle types have been shown to induce inflammation leading to diseases such as fibrosis and cancer (e.g. silica and asbestos)[25]. In toxicology studies the ability of such particles to induce toxic effects is related to dose and a number of physico-chemical properties such as size, shape, chemical composition, surface reactivity, surface charge, solubility/bio-durability etc. Recent studies have suggested that there may be key physico-chemical characteristics, other than length mentioned earlier, related to the surface of particles such as the specific surface area of the particles[26], surface reactivity[11], surface charge[27] and capacity of the surface to form free radicals[28], that induce inflammation and toxicity. For more complex particles such as air-pollution particles and some manufactured ENP, insolubility of compounds are likely to be important (reviewed in[29]). From thermodynamic principles it is logical to conclude that surface reactivity may change with particle size for any material and that the unit mass and chemical reactivity (as well as thermodynamic instability) of a compound increases as particle size decreases, often resulting in changing polymorphs as a function of size[30].

A review study (REFNANO) sponsored by the UK government (www.defra.gov.uk/environment/chemicals/achs/070605/ACHS0709A.pdf) has identified a list of physico-chemical characteristics relevant to toxicology of ENP such as size and shape; surface properties like area, charge, porosity and chemistry; agglomeration/aggregation etc. The methods and instrumentation (e.g. SEM, TEM, Nanosight) for measuring these properties are growing. This topic is attracting the interest of different parties such as the OECD and NIST. However, central to this topic are concerns about: the verification of the characterisation methods and the ability to characterise ENP in different media (e.g. cell culture media or
body tissues). These concerns must be addressed in any reliable ENP characterisation exercise.

**Exposure Assessment**
To assess exposure is to determine the exposure setting (occupational, environmental, consumer); the route of exposure (inhalation, ingestion, dermal); the extent of exposure (the level, duration and the frequency) and depending on the exposure setting, the population exposed. An exposure scenario describes the conditions in which an exposure event which occurs within a setting, affecting a certain route, at a certain extent, for an individual or a subgroup within the exposed population. To assess exposure is to identify and quantify the exposure scenarios of interest.

Currently there is a near complete absence of data concerning exposure to nanomaterials in an occupational or consumer context[6] and there is much uncertainty regarding the information on ENP exposure. The current approach in the new EU regulatory framework REACH (Registration, Evaluation and Authorisation of Chemicals http://ec.europa.eu/environment/chemicals/reach/reach_intro.htm ) is based on a tiered approach. This approach consists of a conservative first tier followed by a more realistic second tier. A model for the Tier 1 approach is the EASE model (http://www.hse.gov.uk/research/rrpdf/rr136.pdf) developed initially to be the underpinning model for the exposure assessment in relation to new and existing substances regulation. EASE is based on a decision tree structure and has been widely criticised for being too conservative. For consumer exposure the CONSEXPO model is intended for use in REACH (http://www.rivm.nl/en/healthanddisease/productsafety/ConsExpo.jsp).

In the event that the first tier approach is unacceptable (because of unrealistic exposure estimates) a second tier approach is required. This would involve actual exposure measurements and/or use of an improved exposure model. For occupational exposure there is currently no accepted second tier model for REACH, although work is underway to develop an improved modelling approach to address this issue. This approach uses Monte Carlo simulation model to estimate exposure variability/uncertainty and Bayesian methods to combine the output from the probabilistic model with real exposure data to produce improved estimates of exposure for risk assessment. This approach is known as the Advanced REACH Tool (ART)[31]. While EASE and CONSEXPO are readily available, it is important to note that neither model is currently directly applicable to ENP.

**Risk Assessment**
Different approaches to assess the health risk for ENP were recently proposed. For example, control banding tool for risk level assessment and control of nanoparticle exposure[32]. However a quantitative risk assessment of ENP is not yet accomplished. The traditional Risk Assessment process outlined by REACH, involves the use of toxicology data to obtain the Derived-No-Effect-Level (DNEL) of exposure (http://ec.europa.eu/enterprise/reach/docs/reach/volume2.pdf).

Risk is assessed by comparing the DNEL with the exposure levels obtained from the different scenarios in the exposure assessment.

**Uncertainty Analysis**
Given that the knowledge of ENP exposure and toxicity is incomplete, the risk assessment of ENP is bound to be clouded in uncertainty. Uncertainties in the exposure and dose-response information may result in unrealistic risk estimates. For exposure, some sources of uncertainty are: (i) lack of precise knowledge of potential exposure scenario and (ii) distributional uncertainty of
the exposure factors or parameter values (i.e. there is a range of values representative of the parameter). For dose-response, inadequate human/animal data, inappropriate dose-response models and the lack of biological basis for the adverse effects are some of the sources of uncertainty. However by quantifying uncertainty, Uncertainty Analysis (UA) provides a yardstick to measure how ‘conservative’ the risk estimate(s) is. In UA the potential sources of error (data gaps, assumptions and bases of judgement) are identified for each step in the risk assessment and their overall impact on the risk estimate(s) is evaluated quantitatively. Knowledge of uncertainty in the risk assessment will help risk assessors to make more informed and reasoned risk-based decisions. UA is therefore an essential tool for Risk assessment of ENP.

For ENP, quantitative Risk Assessment would start with the deterministic PBPK/PD model of the exposure-dose-response relationship and its extrapolation, using data from in vitro to in vivo and to human situations. However, the exposure-dose-response model will be affected by the variability in the data and the uncertainty in each of the contributory steps. The deterministic model will be extended into a probabilistic model and a Monte Carlo Simulation (MCS) approach will be used to generate probabilistic risk estimates[33] by assigning probability distributions to the model parameters. Model simulation will be run repetitively, each time with a different value for a parameter chosen from its distribution, to obtain a frequency distribution or cumulative density function for the model output. Specifically, by incorporating uncertainty in the modelling process for ENP risk assessment the end result will a distribution of DNEL values instead of a single risk estimate as in the deterministic (traditional) risk assessment. Together with the exposure level (also presented as a distribution) obtained from the probabilistic model of exposure (see Exposure Assessment) risk estimates will be evaluated for risk assessment. This approach can be used to identify central tendencies (expected risk) and associated high-end exposure with their probability of occurrence. Clearly the risk estimates are dependent on the extent of uncertainty. However, by doing the UA with a sensitivity analysis, it is possible to identify the factors which contribute most to the overall model uncertainty. Steps would then be taken to obtain more information on these factors to reduce uncertainty. This approach is yet to be applied to ENP.

Risk Management
The generic steps for risk management are: (a) Risk Assessment, (b) Risk Avoidance; (c) Risk Retention, (d) Risk Transfer and (e) Risk Reduction. The Risk Assessment process is described in details above. Once the Risk is assessed, the next decision is whether this Risk can be eliminated or avoided entirely. If this is not possible then the next step is to consider whether the Risk can retained – i.e. absorbed. This involves accepting the loss caused by the adverse event when it occurs. Risk retention is a viable strategy for small risks where the cost of insuring against the Risk would be greater over time than the total losses sustained. If this option is not viable then the following step to consider is Risk Transfer. This process involves transferring the risk to other parties and therefore mitigating, compensating the cost of the Risk (e.g. Taking insurance policy). For the potential health risks associated with ENP none of the above steps are viable so Risk Reduction must be considered.

The three steps to Risk Reduction are: (1) Identify the stakeholders; (2) Set the regulations for exposure standards and implement the prevention/intervention measures to minimise Risk; (3) Prepare and implement a communication strategy to inform the identified stakeholders.

---

---
3. Conclusion

The possibility for translocation (and accumulation) into different body organs following exposure to potentially toxic ENP plus the limitation of the current regulatory risk assessment tools, as reviewed above, have posed a new challenge on how to best assess the risks from exposure to ENP[4]. It is clear that we must seek solutions beyond the state-of-the-art for an effective risk assessment in this area. To address this challenge, the preferred approach must:

1. investigate the cellular and molecular mechanisms underlying the observed association for a range of body systems (such as Pulmonary, Cardio-Vascular, etc.);
2. develop in vitro screening systems, verifiable with in vivo models of healthy and diseased (susceptible) individuals (using genetically modified mice) and validated in a round robin test between the partners, which could be used as potential high throughput alternative toxicity tests
3. develop in silico models: QSAR-like method to facilitate such identification and use this to predict the hazard of new materials; Exposure models specific for ENP; Extrapolate the results from in vitro to in vivo and to human relevant occupational or consumer situations;
4. develop in vivo models, for verification of the in vitro results which could also be considered as models for toxicity testing of ENP in their own right. These models will use significantly less animals than the current standard regulatory tests and therefore help to refine and reduce the number of animals used for toxicity testing of ENP. Also, these tests could be useful for ENP not used in cosmetics products.
5. incorporate all relevant data as part of model construction and conduct Uncertainty Analysis as an extension of the traditional risk assessment paradigm to ENP.

4. An Engineered NanoParticle Risk Assessment (ENPRA) Approach

It is clear that there is a need for an ENPRA approach. The principal aim of ENPRA is to develop and implement a novel integrated approach for ENP Risk Assessment. This approach is based on the Exposure-Dose-Response Paradigm for ENP (Figure 2). This paradigm states that exposure to ENP of different physico-chemical characteristics via inhalation, ingestion or dermal exposure is likely to lead to their distribution, beyond the portal-of-entry organ to other body systems. The cumulative dose in a target organ will eventually lead to an adverse response in a dose-response manner.

![Figure 2](image-url)
- **Hazard Identification**: it will be necessary to implement a comprehensive set of measurements of the physico-chemical characteristics of ENP, both in bulk samples and in body tissues establishing common protocols for ENP characterization.

- **Dose-Response Assessment**: in vitro testing systems using models representing the most important target systems affected by ENP can be implemented should be implemented.
  - These *in vitro* tests need to be verified with *in vivo* models, (carefully designed to minimize the numbers of animals used and/or their inconvenience).
  - The selected *in vitro* tests could then be integrated as part of a low-cost, high-throughput screening *test system*, as a cost effective way of testing a large number of ENP expected to enter the EU market in the near future.
  - The *in vitro* data will be used to develop a QSAR model linking ENP characteristics with the adverse effects.

- **Exposure Assessment**: after reviewing existing exposure models in the public domain it will be necessary to construct a model of ENP exposure in occupational settings. The traditional risk assessment approach will be extended by quantifying the *uncertainty in ENP exposure*.

- **Risk Assessment**: It is very important to extend the current risk assessment approach to ENP by building particular and appropriate mathematical models of exposure-dose-response, including uncertainty analysis.

The approach proposed by ENPRA is in line with the grand challenges described in the article in *Nature*[4]. The rationale of ENPRA is summarised graphically in Figure 3.

---

**BIBLIOGRAPHY**

2. Hood, E. Nanotechnology: looking as we leap.

4. Maynard, AD; Aitken, R. J; Butz, T; Colvin, V; Donaldson, K; Oberdorster, G; Philbert, MA; Ryan, J; Seaton, A; Stone, V; Tinkle, SS; Tran, CL; Walker, NJ; Warheit, DB. Safe handling of nanotechnology. *Nature*, 2006, (444) 267-269.


8. Dick, CA; Brown, DM; Donaldson, K; Stone, V. The role of free radicals in the toxic and inflammatory effects of four different ultrafine particle types. *Inhalation Toxicology*, 2003, (15) 39-52.


11. Duffin, R; Tran, CL; Brown, DM; Stone, V; Donaldson, K. Pro-inflammogenic effects of nanoparticles in vivo and in vitro: highlighting the role of particle surface area and surface reactivity. *Inhalation Toxicology*, 2008, (19) 849-856.


17. Singh, R; Pantarotto, D; Lacerda, L; Pastorin, G; Klumpp, C; Prato, M; Bianco, A; Kostarelos, K. Tissue biodistribution and blood clearance rates of intravenously administered carbon nanotube radiotracers. *Proceedings of the Natural Academy of Sciences USA*, 2006, (103) 3357-3362.

18. Kim, Y; Kim, J; Cho, H; Rha, D; Kim, J; Park, J; Choi, B; Lim, R; Chang, H; Chung, Y; Kwon, I; Han, B; Yu, I.
Twenty-eight-day oral toxicity, genotoxicity, and gender-related tissue distribution of silver nanoparticles in Sprague-Dawley rats. Inhalation Toxicology, 2008, (20) 575-835.


26. Tran, CL; Buchanan, D; Cullen, RT; Searl, A; Jones, AD; Donaldson, K. Inhalation of poorly soluble particles. II. Influence of particle surface area on inflammation and clearance. Inhalation Toxicology, 2000, (12) 1113-1126.


INTEGRATION OF THE ENVIRONMENTAL DIMENSION INTO OCCUPATIONAL RISK PREVENTION

Companies are duty bound to protect the working environment but also the broader environment per se. This article sets out to examine the responses offered by Spain’s legal system to the problem of occupational and environmental safety, mindful of the need to deal with these two questions jointly and in unison. This in turn will offer an up-to-date view of risk-management and environmental-protection systems as a means of optimising occupational health.

By Rosa María Morato García. Assistant Professor. Department of Labour Law and Social Work. Law School. Campus Unamuno. Universidad de Salamanca. email: morato@usal.es

All productive activity is intrinsically hazardous and it is not possible to avoid all health and safety risks. Even though this is the initial and pragmatic premise that we need to work from, there is still a real, central and overriding concern that we cannot shirk: the protection of workers in their working environment and the impact of the business activity on the natural environment. Indeed, the great majority of these situations in which occupational health and safety comes to be gravely jeopardised result from a concatenation of diverse factors that spill beyond the immediate work setting and the conditions pertaining to any particular workplace. There are unquestionable links between occupational health-and-safety legislation and the environment in the broadest sense. There are therefore countless reasons why occupational-risk-prevention legislation should also take on board the natural environment among its set of preoccupations.

Integral nature of preventive and environmental policies

As a starting point for this analysis we need first to make it clear that there is a set of mutual interactions between the external environment, in the traditional sense and the internal or working environment.

- First and foremost the overlap between occupational risks and environmental risks is palpable in those cases in which the threat that might hover over the health and safety of the workers does not stem from the actual productive process carried out in the firm in question. On the contrary it is the result of any circumstance outside the obligations strictly incumbent on the working environment and work organisation. The clinching factor here, however, is that this threat, albeit external, actually manifests itself during the
work that this particular worker is asked to perform. These phenomena might by hydrological, meteorological, geophysical or biological in nature and although they originate from outside the workplace they manifest themselves inside it.

Mention must also be made of those other circumstances in which the workers are subject to substantial levels of hazardousness when working outdoors or in direct and immediate contact with the natural environment (for example fire fighters, farmers and construction workers affected by adverse weather conditions). It is unlikely that the environment-based risk factors faced by these groups can be completely obviated, either because the current levels of knowledge, techniques and practice cannot fully cope with them or because the very nature of the jobs these workers have been hired for necessarily calls for these risks to be assumed as part and parcel of their tasks. This irremediable and, to some extent, permitted risk must, however, be duly identified, assessed and submitted to the proper measures of control so that it might be mitigated as far as is absolutely possible.

- As well as filtering in risks from outside, the firm, conversely, also acts as a generator of risks from the inside out. The materials and procedures employed by the firm (such as the handling of hazardous substances like explosives or substances of a flammable, corrosive sensitising, carcinogenic or mutagenic nature), as well as any failures in the internal or factory-level environmental protection system might have harmful effects on the health and well-being of the workers themselves and even of the public at large when the effects of the production system spill beyond the firm itself. Serious environmental damage might then ensue, such as air pollution, water or soil contamination, a build up of waste or loss of biodiversity. Witness the grave environmental effects that might be caused by the waste disposal and water treatment industries, nuclear power plants, the chemical industry or activities using chemical products such as the metal industry or the car industry, cleansing, pharmaceutics, construction, textiles, farming, etc.

For our purposes here, therefore, companies can be outside-in filters of threats to occupational health-and-safety and also inside-out agents of harm to the environment. They must therefore be included as an essential part of the solution. Against the rather passé idea that stable and permanent economic development is at loggerheads with the conservation and maintenance of natural resources, it is now essential to lay down the basis of a productive activity based on the postulates of «sustainable development » (1).

And the truth is that an active concern for the natural environment not only reflects positively on the peoples’ living conditions, and particularly in the working conditions of productive personnel, but also has significant knock-on benefits for the whole business set-up, as measured in terms of efficiency and profitability. This is so first and foremost for reasons of pure logic: business production feeds on natural resources and their exhaustion represents a huge obstacle not only for economic growth but also for subsistence itself. Secondly, environment-friendly business policies improve the image of the business in question and give it a competitive edge over other firms (2).

The upshot of all this must be the realisation that no false wall can be raised between the aforementioned internal and external aspects. Risk management systems and environmental protection
systems have to be regarded as inextricably mixed and treated accordingly (3)

**Legislative basis for integral risk management**

Any company’s concern for the environment is seriously hampered by existing differences in environmental legislation between the various member states of the European Union and also the uneven treatment of other matters, such as recognition of worker-representatives’ right to promote worker involvement in risk prevention and environmental decision-taking procedures. Nonetheless, mention must be made here of article 3.3 of the Treaty on European Union (in the consolidated version OJEU C 115, 9 May 2008), which lays down the Union’s remit to work for «the sustainable development of Europe» based on «balanced economic growth» and also «a high level of protection and improvement of the quality of the environment». And among the principles which are to guide the Union’s action, article 21.2.f says that it shall «help develop international measures to preserve and improve the quality of the environment and the sustainable management of global natural resources, in order to ensure sustainable development».

Furthermore, article 6 of the Treaty Establishing the European Community (consolidated version, OJEU C321E, 29 December 2006) evokes the need for environmental protection requirements to be integrated into the definition and implementation of the set of Community policies and actions, while article 191.1 and 2 of the Treaty on the Functioning of the European Union lays it down that the Union’s policy on the environment shall contribute, among others, to the following objectives «preserving, protecting and improving the quality of the environment; protecting human health; the prudent and rational use of natural resources and promoting measures at international level to deal with regional or worldwide environmental problems, and in particular combatting climate change».

Zooming in from Community to Spanish law, we find significant links between section 45.1 of the Spanish Constitution (inspired generally on the pronouncements of the Stockholm Conference) and occupational risk prevention matters as dealt with herein. It is hence essential that labour law and environmental law should complement and enrich each other reciprocally. Nonetheless, references to the external environment are few and far between in the main labour laws. The Spanish Occupational Risks Prevention Act (Ley de prevención de riesgos laborales: LPRL hereinafter) sets up a complete legal system around the workers’ right to enjoy efficient health-and-safety protection (article 14.1). But it restricts its concern exclusively to the occupational risk and the employer’s obligation to guarantee the existence of safe working conditions insofar as this may be necessary to preserve workers from harm in carrying out their professional activity. In keeping with our arguments so far, however, the truth is that no interpretation can afford to restrict itself solely to the internal aspects and ignore the need for joint treatment of the two risks, the purely occupational risk and the environmental risk. These two risks may at times follow different paths but they are both liable to cause grave harm to workers’ health, not only as productive agents, but also, and especially, as citizens and consumers.

Quite on the contrary, express mention must be made of the powers and responsibilities given by the Statute of Workers’ Rights (Estatuto de los Trabajadores) to the workers’ elected representatives in article 64.2 as amended by Act (Ley) 38/2007 of 16 November (Official State Journal [BOE in Spanish initials] of
17 November). With the aim of bringing its provisions into line with Directive 2002/14/EC of the European Parliament and of the Council of 11 March 2002 establishing a general framework for informing and consulting employees in the European Community, the Spanish Act establishes the right of the workers’ committee to receive quarterly reports not only of the general economic trend of the sector the company concerned trades in but also, and here it breaks new ground, on its economic situation «and the recent and probable future trend of its activities, including any environmental measures that may impinge directly on employment» (Article 64.2.b).

Furthermore, a detailed perusal of prevention legislation shows a concurrent interest in the natural environment. The objectives of some of these laws do indeed openly embrace the principle of avoiding harmful consequences to the environment, thus beginning to heal the glaring rift between occupational and environmental safety (4).

In short, there is now a need for public policies that lay down the general framework for preventive action. Public powers are responsible, precisely, for promoting diverse investment and incentive initiatives to make prevention, correction and control of the environmental impact of industrial activities truly feasible. Some of the most obvious measures involved here are energy efficiency and saving programmes, water treatment programmes, the implementation of less polluting technologies and the promotion of environment-friendly transport systems (5).

But the truth is that the broadest possible environment-based conception of risk prevention involves not only the public powers; it also calls for shared responsibility from all stakeholders and groups across the board, from workers themselves and the public at large. It is also crucial, moreover, for trade unions and environmental organisations to pitch in. Indeed, in view of the fact that the productive activity is largely responsible for ongoing environmental degradation, it behoves the business world to adopt measures and mechanisms designed to knit environmental concerns into the overall fabric of labour relations. This would help to redress the considerable backwardness that exists on this score, particularly in Spain.

It is therefore essential for companies’ risk prevention policies to be geared also towards the natural environment. It is a question, in short, of successfully and harmoniously reconciling businessmen’s goals of competitiveness and profitability with the sustainable development goals of environmental management.

**Co-responsibility and participation**


- Commission Recommendation of 7 September 2001 allowing voluntary participation by organisations in a Community eco-management and audit scheme (EMAS): «Involvement of all in the environmental work is a chance and an opportunity to work in a more effective way and is the prerequisite for success » (Annex II)

- «Green Paper on adapting to the climate change in Europe: Options for EU action» [Brussels, 29 June 2007 COM (2007) 354 final]: «Companies will need to adapt to changing conditions for example by integrating climate change adaptation needs into their business plans». This explains why one of the four pillars for EU action in said document is ensuring the involvement of European society, business and the public sector «in the preparation of coordinated and comprehensive adaptation strategies ».
Environmental management in the workplace

It is the remit of the employer above all to provide healthy working conditions that guarantee the health and psychophysical well-being of workers. This bald statement leads us on to an analysis of the measures that should be applied by business management to avoid and prevent risks of all type (whether intrinsically occupational or generated outside the workplace). A proactive attitude by the firm is essential to ensure the real and effective implementation of environmental improvements and to achieve the yearned-for goal of sustainable development. But this can be done only by giving top priority to the principle of risk prevention (occupational and environmental), thereby definitively setting up a business outlook that seeks not only to provide a safe and healthy working environment but also strives to use all available measures to guarantee the conservation and protection of the broader environment, by dint of a suitable environmental management of the post productive process. This would call for all the following:

- Risk identification and assessment needs to take in also such environmental risks as the firm might cause. This is where impact assessments come into their own, to address problems that threaten the external environment and working conditions, establish the causal links between them and involve all stakeholders in the company’s productive strategy.

- Immediately after detection of the risks liable to harm the natural environment, the next essential step is to plan a coherent and integral set of preventive measures in keeping with said environmental risks (such as setting up a waste recycling plan and sustainable resource-use plan).

- Alternatives need to be sought and defined for optimising the company’s environmental performance (e.g. undertaking to replace polluting production systems and technology by cleaner alternatives or replacing normal workplace commuting systems by other more environmentally-friendly means of transport) and making firm commitments to eradicate any environmentally unfriendly practices.

- A monitoring system has to be set up for keeping a track of occupational risks and checking the effectiveness of environment protection measures. This monitoring system would be continually updated in line with changing risk factors and technological advances that might help to avoid or mitigate them. Vitally important here are environmental audits, carried out throughout with the participation of the workers’ committee and trade union sections.

- Material and human resources have to allocated as necessary for environmental risk management purposes.

- Finally, the participation of workers and their representatives in the company’s environmental activity is vital.

It can safely be said in this field, therefore, as in so many others, that simple plans and good intentions are not enough. Companies are bound to comply with all environmental legislation and also have to show the will to reach global and integral environmental-protection agreements with all stakeholders. Equally essential is the staunch commitment by workers and their representatives and trade union organisations to collaborate and participate in all environmental management matters. As might well be imagined this will call for proper, in-depth worker training in the
environmental implications of their work, mainly dealing with the type of activity carried out by the firm and also the substances and materials used in production.

**Participation arrangements for improving environmental performance and the protection of workers' health and safety**

Many measures undoubtedly play a key role in ensuring the effectiveness of occupational risk prevention and environmental management. Particular mention here must be made of the various worker participation arrangements through workplace representation organisations. It must also be pointed out, however, that the effective implementation of this participation is unlikely to be trouble free, despite the progress made in recent years. It goes without saying that collective negotiation procedures need to take these contents and measures more fully on board and broaden their sphere of action. The aim in so doing would be to fulfill all the following objectives: slashing work accident rates; promoting and improving working conditions so that life- or health-threatening situations can be headed off beforehand and working jointly to safeguard the wider environment outside the workplace.

In default of any explicit legal mention of the workers’ right to take part in environmental management, collective negotiation has done a sterling and largely supererogatory job in recent years in terms of allocating powers and responsibilities in this field. The achievements are still modest. Even so, due credit must be given to the significant contribution being made by sector-based agreements and collective bargaining agreements in breaking down any barriers that might exist between labour law in general and environmental law. The number of sector- or company-based agreements that give a systematic treatment to environmental matters is slowly but steadily increasing. These agreements have also laid down a body of cross-industry regulations giving a clutch of responsibilities on these matters to elected or trade union representatives, on the one hand, or environmental or prevention delegates on the other.

Working from the principle that participation in preventive policies and activities is the best guarantee of its effectiveness and the main driving force behind improvement of health and safety protection at work, there is in fact a growing body of collective bargaining agreements that, exploiting all the legal leeway allowed them, have broadened the duties and powers of specific occupational-risk-prevention representatives to take in environmental powers and responsibilities as well (6). Others have opted to go down a different road and set up a new arrangement of *ad hoc* participation inside the firm to knit the strand of environmental concern into the world of labour relations. This option is allowed under Article 35.4 LPRL but on a disconnected basis, and herein lies the main objection from a prevention viewpoint (against occupational risks) since it raises barriers to the integration of both concerns. One of the best examples is Article 67 of the Fifteenth Chemical Industry Collective Bargaining Agreement (BOE 29 August 2007), where workers’ representatives are empowered to designate an **Environment Delegate** with specific duties and responsibilities in the environmental field (7). Several agreements in this sector and also other sectors have since followed suit, normally involving the implementation of a **Joint Committee for the Prevention of Occupational and Environmental Risks** (8). Its powers and responsibilities include watching out for compliance with environmental legislation; vetting the use of raw materials,
natural resources and energy to ensure the best use thereof; distributing environmental information among the workers and, finally, the right to be consulted by company management.

There is no doubt that collective negotiation is an invaluable means of reaching agreements in this direction, to flesh out the minimal preventive legislation and lay down the master lines of specific environmental training. Indeed, the unified collective-negotiation criteria and objectives for the two Spanish trade unions UGT and CCOO in 2001 included a call for state-level sector-based agreements to include a minimum 2-hour environmental course among the training arrangements. Even so the attention paid to this matter is still insufficient. This study has focused on the exceptions, but by and large there are few collective bargaining agreements that have built on the original agreement and recognise the workers’ right to receive information on the firm’s environmental performance and environmental training. Certain highly polluting industries, key and strategic sectors were trailblazers in phasing into company policy a groundbreaking and interesting conception of environmental culture as a concern falling within the company’s remit, establishing it as an object of protection alongside the health and safety of its staff. That said, the promising developments made in recent years should not blind us to the fact that the legislative provisions do not always correspond to a firm commitment to continual improvement in the firm’s environmental performance and the defence of environmental values. Some collective bargaining agreements there are, for sure, that pay only lip service to environmental concerns without ever putting into operation any real measures to that end (9).

What is of interest for our purposes here is to witness how environmental concerns are gradually being brought into the negotiation terms of collective bargaining agreements, for all the idiosyncrasies there might be in the contents of each one studied. This development is likely to pick up speed and momentum in the future, in keeping with the importance and worth of the matters being dealt with.

Grave and imminent risk posed by the natural environment

We now need to deal with another of the many varied aspects of environmental protection, seen in the broadest sense, and workers’ rights, namely the existence of a grave and imminent risk from the natural environment and its possible effect on occupational safety. In this context we also need to look at the employers’ obligations for dealing with this threat, as laid down in article 21.1 LPRL and the workers’ exercising of their right to interrupt their activity in these circumstances, as provided for in 21.2 LPRL. We make this analysis on the clear understanding that behind said risk often lies the action of man, normally in terms of his industrial activity. For what we are dealing with here is a two-way process. The action of the firm, in one way or another, deteriorates and pollutes the soil, the air, rivers and the sea, wild flora and fauna, both in its bona fide function (due to the consumption of air, emissions, waste and the release of toxic substances from the productive process) and in its clandestine function (through illegal discharge into natural waterways, for example). These factors worsen the minatory climate change, which is profoundly upsetting all the thermal and climatologic cycles and is behind many of the violent weather events of recent years, which in turn represent a risk to the safety of one and all, workers included.

As a starting point we should point out that in situations of grave
and imminent risk (Article 4.4 LPRL) the employer is bound to perform a series of planning measures and implement them:

- Set up an effective, fluid and transparent communication system between the various management levels to head off possible danger situations.
- As soon as possible communicate the existence of a risk of such characteristics to all affected workers and inform them of which measures have been taken and shall be taken in these cases. It is therefore necessary to draw up emergency plans with action protocols for dealing with such situations by means of measures of diverse scope.
- Give instructions so that workers who cannot contact their line bosses can take appropriate measures in the event of a grave and imminent risk.
- Make due arrangements for interrupting productive activities when there is a «grave, imminent and inevitable» risk and keep it in abeyance for as long as the danger lasts. An exception is made, of course, for renewal of activities when required for safety reasons or obliged by law.

Environmental provisions in collective bargaining agreements

Information

- Article 30 of the 4th Collective Bargaining Agreement for Tiles and bricks (BOE 15 August 2007).
- Article 72 of the 4th Collective Bargaining Agreement for Cement (BOE 18 October 2007).

They agree on the creation of «specific training programmes on these matters to enhance the knowledge of environmental problems».

Training

- Articles 36 and 37 of the 2nd Collective Bargaining Agreement for optical fiber cable (BOE 23 September 2004).

It is proposed that a «manual of good environmental practices» be drawn up and distributed among the workers, establishing their right to receive environmental training «not only in general awareness-raising aspects but also in specific subjects of a technical and legislative nature » and the inclusion thereof in the company’s training plans (which
The moot point now is whether workers are entitled to break off their work if they become aware of a grave and imminent risk threatening their life or well-being, arising from environmental conditions surrounding the work performance site. The answer is unequivocally "yes". Occupational health and safety legislation was drawn up largely with the aim of protecting workers from «occupational risks» that might lie in wait for them precisely while carrying out their work in the firm. And the truth is that the LPRL also eschews any mention of the employer's environmental safety duty.

It should immediately be pointed out here that any dichotomous perception of the occupational risk prevention system and the environmental system is completely inappropriate. Environmental factors are only one more of the factors surrounding the worker. This is precisely why a more open and flexible prevention policy is needed, conducive to a complementary treatment of occupational health and safety problems and environmental safety questions. In this way environmental values would be knitted seamlessly into the occupational health and hygiene system. It is therefore perfectly in order for a holistic vision of the risk to be defended, whereby its very existence would entitle employees to break off their contracted service unilaterally when, in the course of their working day, there are signs of an imminent risk of grave consequences. This is quite apart from the origin thereof, for the stress should always be placed on worker safety. Furthermore, once the worker has taken the decision to break off the work, he or she will be entitled to turn a deaf ear to any pleas from management to renew these tasks for as long as said risk lasts.

- Article 67 of the 15th Collective Bargaining Agreement for the chemical industry (BOE 29 August 2007).
- Article 29 of the Collective Bargaining Agreement for Irrigators (BO Castellón 1 January 2008).
- Article 29 of the Collective Bargaining Agreement for Food (BO Navarre 4 April 2008).

Training is to be held «in the company itself during working hours».

It is proposed that environmental aspects be integrated into training programmes, which will be geared towards environment delegates, prevention delegates and the rest of the workers.

The training is to be held «in the company itself during working hours».)


Article 67 of the 15th Collective Bargaining Agreement for the chemical industry (BOE 29 August 2007).

Article 29 of the Collective Bargaining Agreement for Irrigators (BO Castellón 1 January 2008).

Article 29 of the Collective Bargaining Agreement for Food (BO Navarre 4 April 2008).

The moot point now is whether workers are entitled to break off their work if they become aware of a grave and imminent risk threatening their life or well-being, arising from environmental conditions surrounding the work performance site. The answer is unequivocally “yes”. Occupational health and safety legislation was drawn up largely with the aim of protecting workers from «occupational risks» that might lie in wait for them precisely while carrying out their work in the firm. And the truth is that the LPRL also eschews any mention of the employer’s environmental safety duty.

It should immediately be pointed out here that any dichotomous perception of the occupational risk prevention system and the environmental system is completely inappropriate. Environmental factors are only one more of the factors surrounding the worker. This is precisely why a more open and flexible prevention policy is needed, conducive to a complementary treatment of occupational health and safety problems and environmental safety questions. In this way environmental values would be knitted seamlessly into the occupational health and hygiene system. It is therefore perfectly in order for a holistic vision of the risk to be defended, whereby its very existence would entitle employees to break off their contracted service unilaterally when, in the course of their working day, there are signs of an imminent risk of grave consequences. This is quite apart from the origin thereof, for the stress should always be placed on worker safety. Furthermore, once the worker has taken the decision to break off the work, he or she will be entitled to turn a deaf ear to any pleas from management to renew these tasks for as long as said risk lasts.

The training is to be held «in the company itself during working hours».)


Article 67 of the 15th Collective Bargaining Agreement for the chemical industry (BOE 29 August 2007).

Article 29 of the Collective Bargaining Agreement for Irrigators (BO Castellón 1 January 2008).

Article 29 of the Collective Bargaining Agreement for Food (BO Navarre 4 April 2008).

It is proposed that environmental aspects be integrated into training programmes, which will be geared towards environment delegates, prevention delegates and the rest of the workers.

The training is to be held «in the company itself during working hours».)


Article 67 of the 15th Collective Bargaining Agreement for the chemical industry (BOE 29 August 2007).

Article 29 of the Collective Bargaining Agreement for Irrigators (BO Castellón 1 January 2008).

Article 29 of the Collective Bargaining Agreement for Food (BO Navarre 4 April 2008).

It is proposed that environmental aspects be integrated into training programmes, which will be geared towards environment delegates, prevention delegates and the rest of the workers.
Definitions (Article 4.2 and 4 of the LPRL)

- **Occupational risk**  
  *Possibility of any worker suffering work-related harm*

- **Grave and imminent risk**  
  *That which is reasonably likely to occur in the immediate future and might entail grave harm to the health of workers.*

**By way of a summary: proposals**

There follows a list of all the conditions sine qua non for adoption of the best risk prevention strategy in firms, in the interests of an effective protection of health and the surrounding environment:

- **Raise awareness of environmental risks and their consequences for the health and safety of citizens in general and workers in particular.** There is a clear and direct relationship between increasing environmental protection and ongoing improvements in the workplace conditions of health, safety and hygiene. As the former improves, so does the latter. Throughgoing commitments therefore need to be taken, leading to the adoption of socially responsible stances towards risk prevention policies (occupational and environmental) and the promotion of a preventive awareness among the workers themselves. This will encourage the adoption of new and less pollutive working and consuming habits (especially in terms of commuting back and forth to work).

- **Establish a habit of dialogue and debate among public and private groups carrying out research into the improvement of working conditions and environmental health.** The spread of preventive attitudes throughout society would help to detect new perils as they arise in the rapidly developing world of work and technological advances as applied to production, thus minimising their impact.

- **At company level there is a need for broadcasting information on the ever-changing problems of an environmental nature, bringing them to the notice not only of their elected worker representatives but also the workers themselves.** Equally positive would be swapping of knowledge and experiences between the various companies of the sector to gain a deeper understanding of the best practices in risk prevention and environmental protection.

- **Environmental training needs to be brought in as part and parcel of the obligatory training to be given by the company, incorporating the learning of these questions throughout the various phases of the education system.**

- **Foment social dialogue and collective negotiation to broaden rights on risk prevention without forgetting the specific needs of the natural environment.** One of the ways of doing this would, without doubt, be the insertion of clauses in collective bargaining agreements to increase worker involvement in prevention policies and activities. If sustainable development is to be made a bigger part of collective bargaining agreements, there will be a concomitant need for worker representatives to be consulted on implementation and operation of the environmental management systems. They will also have to be given powers for making proposals in favour of the prevention of occupational and environmental risks by harnessing the expertise of all the parties involved.

- **Promotion of sustainable mobility systems, encouraging**
workers to commute back and forth to work using low impact modal means of transport. Railway use would of course be encouraged over road vehicle use, so workers would have to be offered attractive and safe alternatives of transport connections with workplaces to discourage the widespread use of private vehicles. Among the most significant trade union proposals, special mention must be made of the serious commitment to public transport (which will call for infrastructure investments, improvement of routes and timetables), improvement of pedestrian routes, use of the bicycle (with an efficient network of bike lanes and bike parks in companies and in commuter trains stations) and the collective use of private vehicles.

- There is likewise a need for rigorous government monitoring of companies’ compliance with environmental legislation, serving to wipe out harmful behaviour once and for all.
- Environmental audits have to be conducted as an essential means of surveillance and control. These audits would involve participation by the workers’ legal representatives and trade unions. Committees would also have to be set up for monitoring the company’s preventive policy and environmental questions.

(1) This idea had already been enshrined in the Rio Declaration (1992) and, practically at the same time, in the «Fifth European Community programme of policy and action in relation to the environment and sustainable development», approved by the European Commission on 18 March 1992 and ratified by the European Parliament and Council of Ministers at the end of 1992.

(2) JORDANO FRAGA, J. La protección del derecho a un medio ambiente adecuado. Bosch, Barcelona, 1995, p. 147.


(4) In chronological order the following legislation advocates the need to take the risks into consideration together, Royal Decree 1254/1999 of 16 July approving control measures for risks inherent to grave accidents involving hazardous substances; Royal Decree 664/1997 of 12 May on the protection of workers from risks related to exposure to biological agents during their working activities (Article 1.4); Royal Decree 665/1997 of 12 May on risks related to exposure to carcinogenic agents (Article 5.4); Royal Decree 374/2001 of 6 April on risks related to chemical agents in working activities (Article 2.5); Royal Decree 783/2001 of 6 July approving the Regulation on healthcare protection against ionising radiation (Title V) and Royal Decree 396/2006 of 31 March establishing minimum health-and-safety provisions applicable to work with risk of asbestos exposure (Article 6, b).


(6) Among others, Article 30 of the Collective Bargaining Agreement for Tiles and Bricks (BOE 15 August 2007); Article 72 of the 4th Collective Bargaining Agreement for Cement (BOE 18 October 2007); Article 106 of the 3rd Collective Bargaining


(9) This aspect is dealt with in greater depth in the study by SASTRE IBARRECHE, R. «La progresiva aceptación del medio ambiente como objeto del convenio colectivo». Tribuna Social, 2005 (175), p. 17.

REFERENCES

1. JORDANO FRAGA, J. La protección del derecho a un medio ambiente adecuado, Bosch, Barcelona, 1995.

2. RIVAS VALLEJO, P. «La protección del medio ambiente en el marco de las relaciones laborales». Tribuna Social, 1999 (103), pp. 9-27.

3. RODRÍGUEZ-PÑERO, M. «Medio ambiente y relaciones de trabajo». Temas Laborales, 1999 (50), pp. 7-17.


FIRE DANGER IN CASTILLA-LA MANCHA UNDER FUTURE CLIMATE-CHANGE SCENARIOS

ENVIRONMENT

Fire occurrence is favoured by flammable vegetation and desiccating climate conditions such as high temperatures, low relative air humidity and drought. The coming climate change is expected to increase the number of heat waves and rainless days; this will tend to desiccate living and dead vegetation and make it more flammable. Furthermore the danger periods and extreme situations are likely to increase with time. That being so, there is now a pressing need to assess how fire danger might vary in the future, doing so with as much spatial detail as possible. This article sums up the results of a research project into the present and future fire danger in the region of Castilla-La Mancha. A study has been made of the region’s recent fire history. Fire weather risk is mapped against different end-of-twenty-first-century climate-change scenarios and an estimate is made of how long the fire alert and risk period will last in Castilla-La Mancha. Finally, some considerations are made on adaptation options and most important research needs for addressing the likely climate-change impacts on the growing danger of forest fires.

By Moreno JM*, Urbieta IR, Zavala G, & Martín M.
Environmental Science Department.
Universidad de Castilla-La Mancha (UCLM).
Avenida Carlos III s/n, 45071 Toledo.
*Corresponding author: JoseM.Moreno@uclm.es

Forest fires are one of the most influential factors on a great part of the earth’s ecosystems [1]. The relations between the climate, underlying meteorology and fire have been well established: fires tend to break out in places that are neither very wet nor very dry. In over-wet areas it would be difficult for fires to start and spread; in over-dry areas there would not be enough fuel to keep them going. It is therefore the in-between zones, with sufficient productivity to produce abundant vegetation but also with long dry periods, that are most fire prone. The Mediterranean climate fits this pattern perfectly, so the Mediterranean areas in general, and particularly the south of Europe, record a high fire incidence [2,3].

Climate change and forest fires have always borne a close relationship with each other in the past, more fires breaking out in the warm periods than in the cold [4]. In Spain the frequency of fires rose during the Holocene period (about 10,000 years ago), recording 100-200 year peaks as the climate became drier [5]. The irruption of man produced an increase in the frequency of fires and an alteration in the dominant vegetation [6]. Fires have continued to occur in historical times, although the changes
in their frequency and in the dominant species suggest that most were the result of land management. Since the second half of the twentieth century an increase in forest fires has been observed, spreading from only a few fire-prone points to practically the whole of Spain. This trend has coincided with the abandonment of the countryside and afforestation of large expanses of land, especially in the northwest, centre, east coast and southwest [7].

The climate has a big say in the ignition and spread of forest fires; aridity indices or high temperatures are good indicators of fire occurrence [8,9]. Under the looming climate-change scenarios, high temperatures and rainless days are set to become more frequent, especially in the Mediterranean type ecosystems in the south of Europe, which will be hit very hard [10]. Droughts are also expected to increase, with an imminent impact on fire danger [11]. In view of these prospects we now need urgently to assess how fire danger might vary in the future, doing so with as much spatial detail as possible.

**Objectives**

The aim of this study is to analyse the recent history of forest fires in Castilla-La Mancha and to ascertain the current fire weather risk in the region and its future variation in different climate-change scenarios. The first step in this process was to analyse the trend in the number of fires and total burnt area in recent decades, as well as the main causes of the fires in the region. A forecast was then made of how drought indices and fire weather risk will vary in the future, using different circulation models and emissions scenarios (IPCC scenarios A2 and B2) in different seasonal periods throughout this twenty first century.

**MATERIAL AND METHODS**

**Fire Database**

A cull was made of the General Forest-Fire Database (Estadística General de Incendios Forestales: EGIF) of the Spanish Environment Ministry (Ministerio de Medio Ambiente: MIMAM) for two periods: 1975-2000, with daily fire figures for the region under study. The daily information includes the number of fires bigger than one hectare, the total burnt area, the date it broke out and the causes. Information on the number of fires per day and the total burnt area was spatialised in a 50 x 50 Km cell-size grid covering the whole region of Castilla-La Mancha.

**Calculation of present and future fire risk**

The close relationship between climate and the state of the fuels means that the fire danger indices currently in use, such as those of the Canadian Fire Weather System [12], are based on only a few weather variables: mean temperature (T) (ºC), total rainfall (R) (mm), mean relative humidity (H) (%) and wind speed (V) (Km/h) (see complementary text 1). Fire danger indices try to show how current weather conditions might impinge on fuel state or fire spread once it has broken out. They are valid indices for suppression tasks, giving a good idea of how difficult it might prove to tackle the fire. In general, the number of days with a fire or many fires or large scale fires varies directly with the danger indices; a greater frequency of high indices, therefore, means a greater likelihood of this type of fire breaking out. Recent studies have shown that the Canadian Fire Weather Index (FWI) gives perhaps the best reflection of risk situations, and recommendations have been made for it to be applied to Mediterranean countries [13]. Some countries (France, Portugal) have begun to use it operationally and the Institute for...
Environment and Sustainability of the European Commission’s Joint Research Centre (JRC) draws up various danger indices on a daily basis, including the FWI.

For this study a calculation was made of the Fire Weather Index FWI and the Drought Code (DC), which measures the effect of seasonal drought on fuels. These indices have been estimated for current climate conditions from daily recorded figures for temperature, rainfall, relative humidity and wind speed for the period 1975-2004 (figures furnished by the Joint Research Centre of the European Commission, JRC, Ispra, Italy). To assess the fire danger under different climate-change scenarios, modelled daily climate figures were obtained for the period 2071-2100, on the basis of the forecasts of different circulation models [14]. Forecasts for greenhouse gas emissions scenarios A2 and B2 were selected from different models of regional and global circulation: HIRHAM-HadCM3, HIRHAM-ECHAM4, PROMES-HadCM3, RCAO-HadCM3, and Arpège-HadCM3 (see Complementary text 2). The present and forecast climate figures were projected onto a 50 x 50 Km grid of Castilla-La Mancha, using the nearest-neighbour interpolation method for subsequent calculation of FWI and DC.

Lastly, an estimate was made of the fire alert period (defined as the number of days between the first and last moment of the year when the FWI is at least 15 for 7 days running) and the fire risk period (number of effective days throughout the year on which the FWI meets the above condition), both for the recorded period and future forecasts, to give an idea of how the distribution of days with a real risk of fire outbreak and spread will change throughout the year.

RESULTS

Recent history of forest fires in Castilla-La Mancha

The last two decades show an upward trend of fires in the region, though the number has fallen in recent years (fig. 1). The area burnt per year shows a more variable pattern; the years of the largest burnt area coincide with the years of the biggest number of fires. In the 1991-2007 period fires averaged 242 per year, affecting an average area per year of 12,500 hectares in the whole region. Fire outbreaks and the affected area in Castilla-La Mancha account for between 2% and 6% of the fire incidence in the whole of Spain, representing in some years up to 10% of the burnt area. The fire-affected area corresponds mainly to wooded areas, especially in years with a high incidence of fires, although unwooded areas come into their own in years of lower fire incidence (fig. 1).
The fire incidence is not even throughout the whole region of Castilla-La Mancha; the highest incidence is recorded in wooded areas where extensive agriculture has not been able to take hold because of the hilly ground. Such areas are found in the northwest (Sierra de San Vicente, Montes de Toledo), the south (foothills of Sierra Morena, Sierra de Alcaraz) and northeast (Sierra de Ayllón and Serranía de Cuenca), which record the highest number of outbreaks and the biggest burnt area (fig. 2).

Judging from the figures on fires over 1 hectare in the 1975-2000 period, the human factor plays a key role in their origin. Looking at the most important causes of the fires we find that about 30% were due to negligence (accounting for 27% of the total burnt area) and 19% were due to arson (accounting for nearly 30% of the burnt area). Fires due to natural causes, mainly lightning strike, weighed in with a considerable share (nearly 10%), representing 13% of the burnt area, especially in the mountainous zones in the east of the region (fig. 3). Lastly, 9% of the recorded fires (8% of the burnt area) in the study period were due to other causes and in 33% of the cases (23% of the burnt area) the causes of the fire were unascertainable (fig. 3).

Fig. 1. Trend in the number of fires and burnt area (hectares), showing the proportion of wooded and unwooded area affected by fire annually in Castilla-La Mancha in the 1991-2007 period. Source: EGIF (DGB, MIMAM) with author input.

Fig. 2. Spatial breakdown of number of fires (a) and burnt area (hectares) (b) per decade in Castilla-La Mancha in the 1975-2000 period.
Present and future fire danger in Castilla-La Mancha under different climate-change scenarios

The projection of climate change situations onto the danger indices, using different scenarios and general circulation models for Castilla-La Mancha, show that the drought code (DC), a measurement of the effect of the seasonal drought on fuels, will rise throughout the region by the end of this century, particularly in the south of the region (fig. 4). Likewise the fire weather index (FWI) will increase in the whole region, especially in the western half, probably leading to an increase in fire intensity as the century progresses (fig. 5). The drought effect and fire intensity will increase both for high-emissions scenarios (scenario A2) and low-emissions scenarios (scenario B2), although there are no great observable differences between both predictions (figs. 4 and 5).
The fire weather index will also increase the number of alert periods and fire danger periods in the whole region (fig. 6). This means that the fire-fighting services will have to start their fire-fighting campaigns earlier and spend more time on alert, since the number of high-risk days will increase during a longer fire season. Scenarios with a greater number of adverse weather situations will in all likelihood mean an increase also in the number of occasions when the fire-fighting tasks are of maximum difficulty.

![Fig. 6. Fire alert period (a) and fire danger period (b) observed in Castilla la Mancha during the 1975-2004 period and forecasts for the end of this century (2071-2100) under the A2 and B2 emissions scenarios.]

**CONCLUSIONS**

**Likely impacts of climate change on fire danger**

Recent decades have shown an upward trend in the number of fires in Castilla-La Mancha, probably favoured by a net rise in temperatures and drop in rainfall in the region and also by recent socio-economic changes, such as the depopulation of rural areas and consequent abandonment of crop-growing activities.

Future forest-fire scenarios point to a generalised increase in danger indices, a longer duration of the fire season and greater frequency of extreme situations, which will also last longer (Table 1). These changes will be particularly severe in the south and west of Castilla-La Mancha. Although it is not easy to predict if there will be more or fewer fires, it is likely that future meteorological conditions will favour the occurrence of bigger fires. There will also be a higher frequency of extreme danger situations when it will be very difficult to tackle the fires. To this must be added a change in vegetation, with a greater abundance of shrub species, more sensitive to water stress. All this would seem to be conducive to a situation with higher fuel build up, aggravated by a tendency to abandon the countryside. This will increase the risk of fire-outbreak and spread in the higher areas, where lightning strike is more frequent and is expected to increase in frequency in the future. In view of all these factors, considering also the pattern of climate change and its incidence on plant species distribution and state, fires are likely to become more frequent, more extensive and fiercer.
Table 1. Summary of the main climate-change impacts on the fire regime and fire outbreaks. (Certainty scale 1 to 5).

<table>
<thead>
<tr>
<th>Fire outbreak variables</th>
<th>Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fire danger</td>
<td>*****</td>
</tr>
<tr>
<td>Fire frequency</td>
<td>****</td>
</tr>
<tr>
<td>Maximum fire size</td>
<td>*****</td>
</tr>
<tr>
<td>Intensity</td>
<td>*****</td>
</tr>
<tr>
<td>Risk zones</td>
<td>*****</td>
</tr>
<tr>
<td>Fire season</td>
<td>*****</td>
</tr>
<tr>
<td>Annual variability</td>
<td>*****</td>
</tr>
<tr>
<td>Fires started by human negligence</td>
<td>****</td>
</tr>
<tr>
<td>Fires started deliberately</td>
<td>***</td>
</tr>
<tr>
<td>Fires started by lightning strike</td>
<td>****</td>
</tr>
</tbody>
</table>

The length of the fire season is dependant on the aforementioned weather conditions and varies by zones. Nonetheless, given that man is the main cause of the fires, they might break out even at moments of the year when the general danger level is low. The danger season, therefore, might not necessarily determine the fire season. In those zones where arson is the main fire cause, it is arson activity itself that may determine the fire season rather than any objective climatic factor. It is not possible to ascertain how climate change might impinge on arsonist behaviour, but the sheer persistence of high danger situations will certainly make it easier for arsonist to start fires. The possibility of copycat fires cannot be ruled out. As regards accidental fires, i.e., those caused by fortuitous human behaviour without malice aforesaid, the greater danger level of the climate might make it more likely for ignition sources to break out into an actual fire. Conversely, the population is gradually gaining a greater awareness of the fire problem and this means that the number of ignition sources may fall over time.

**Main adaptation options**

Negative prospects of increased fire outbreaks as the climate change progresses may be offset by improvements in weather forecasting procedures, knowledge of the state of the fuel and prevention and surveillance strategies. Current weather forecasting techniques allow danger situations to be predicted with a few days notice. With the passing of time improvements in forecasting capacities are likely to increase this notice period. An improvement in the danger prediction capacity will be conducive to a better planning of resources and, particularly, implementation of preventive action in sites of greatest danger.

Improvements in surveillance systems, tapping into new technology breakthroughs, will broaden their range and shorten their sighting- and response-times. This will be a great help in the fight against forest fires. Moreover, high-resolution fuel maps will become more readily available together with more information of the weather-related conditions of that fuel (humidity content). All this and other information will also be pooled in geographical information systems (GIS) while the application of fire propagation models will ensure a correct and rapid response. Remote communication techniques and IT
resources will also provide more in situ information, greatly improving the managers’ performance in weighing up the imminent risk and planning the fire-fighting activities.

Furthermore, fuel management techniques (whether by scrub clearance, controlled burns, use of herbivores, use of biomass or others) should progress on the strength of greater knowledge of the plant species and ecosystems involved. This will favour an integrated management of these fuels, giving due consideration not only to fire prevention but also conservation of biodiversity, carbon fixing and the fight against desertification.

Other added risk factors of some importance, albeit difficult to quantify properly, are the upward population trend, socio-economic improvements and the likely increase in the recreational use of the countryside, together with longer periods of outdoor activity as temperatures become more benign. Improvements in education will probably increase awareness of the risk and encourage less dangerous behaviour. There is also a need for reinforcement of fire protection legislation in the urban/forest interface and measures to enforce it, for instance by taking fire risk into account in town planning schemes.

The likely result is that improvements in prevention, risk assessment and surveillance will be able to suppress many of the forest fires before they get too big. Eventually, it will be only those that break out in circumstances of great danger that get completely out of hand.

Complementary text 1. Variables of the Canadian Forest Fire Danger Rating System (van Vagner 1987)(*).

(*NOTE. Fine Fuel Moisture Code (FFMC), Duff Moisture Code (DMC), Drought Code (DC), Initial Spread Index (ISI), Build Up Index (BUI), Fire Weather Index (FWI)

Future lines of research

In view of the growing danger of forest fires, future research should work at projecting GCMs at the necessary time- and space-detail for studying forest fires. Finding out which synoptic situations are most fire prone in different parts of the territory and also the factors that control them, while building up dependable long-term weather information will enable us to predict what the fire season is going to be like.

More information is needed on the interaction between fires and landscape, and this should be factored into land management schemes. Studies should be made of how far danger conditions make the landscape more or less important in fire terms, especially in more vulnerable areas such as population nuclei, infrastructure and protected nature sites. Estimating the hazardousness of the region, with fuel data in tune with seasonal
changes and risks quantified on a worst-case-scenario, will help us to gain a better idea of the risk. We also need more detailed knowledge of how vegetation (fuel) response would vary in extreme situations, especially drought situations. Experimental simulations in various ecosystems would give us a good idea of what to expect in the event of extreme droughts. Evaluation of the climate-related state of fuels and of their biomass at detailed time and space scales is essential for anticipating situations of maximum danger and predicting when and where they are going to occur.

Finally, we know little about the sociological aspects bound up with fire occurrence. There is hence a need for socio-economic scenarios adapted to the real situation of Castilla-La Mancha for improving forecasts of future changes in the fire regime.

Complementary text 2. Description of the greenhouse gas emissions scenarios (IPCC 2007) applied in this study.

- **Scenario A2** of the IPCC (Intergovernmental Panel on Climate Change) assumes a continuously increasing world population. Its most characteristic premises are a world of independently operating, self-reliant nations, with a largely regionally orientated economic development and slower and more fragmented technological changes and improvements to per capita income.
- **Scenario B2** describes a continuously increasing world population but at a slower rate than in A2, with the emphasis on local rather than global solutions to sustainability and with less rapid and more fragmented technological change than in other scenarios.

References

7. Moreno JM, Vázquez A, & Vélez R. 1998. Recent History of


Map of probable locations of future earthquakes for The Iberian Peninsula, the Balearics and Canaries

NATURAL RISKS

Earthquakes do not occur randomly in space; they tend to recur close to previous earthquake sites. This paper draws up a forecast map, based on this fact, for the Iberian Peninsula, the Balearic Islands and the Canary Islands. First of all an analysis is made of the comprehensiveness of the figures to hand on earthquakes in these areas, to weed out the untrustworthy data. A description is then given of a groundbreaking method for calculating the likely distance of the next earthquake from previous ones. A backdated check then shows that this procedure would have efficiently predicted the location of 90% of the earthquakes occurring between January 1985 and April 2009. Lastly, the forecast map for earthquakes after this date is presented.

By ÁLVARO GONZÁLEZ GÓMEZ.
Geology graduate. Diploma holder in Advanced Geology Studies.
Department of Earth Sciences, Zaragoza University.
Alvaro.Gonzalez@unizar.es
http://qmg.unizar.es/alvaro.html

The distribution of earthquakes in space is very complex but not random: they tend to cluster in some regions while other regions never have any (figure 1). This holds true at all levels, from the world as a whole down to small regions (1). This distribution is relatively constant in time: over timescales of decades and centuries earthquakes tend to recur systematically in the same sites. This is because earthquakes happen only where there are faults capable of generating them and specifically where these faults build up the highest tensions (2).

It is not possible at the moment to ascertain exactly where the next earthquake will occur, since their generation is a very complex process and impossible to observe directly. All proposed forecasting methods have chalked up a fair amount of failures in the past, as in weather forecasting. To ascertain the real effectiveness of the procedure it has to be tested not against one particular earthquake but many (3). Forthright claims that one particular earthquake was successfully predicted therefore need to be taken with a pinch of salt.

Only in recent years has a start been made on a thoroughgoing investigation into how far the location of future earthquakes can be predicted simply on the basis of where they have previously occurred (4-6). This simple hypothesis has been shown to be capable of forecasting future earthquake locations as well or better than many more complicated forecasting methods used hitherto (3,7).

The assessment of any region’s seismic risk is always more or
less based on the working assumption that future earthquakes will tend to occur in or close to previous earthquake sites. In general, however, the exact places where these earthquakes occurred have not been taken into account. On the contrary, the usual procedure is to map out the earthquake-prone areas according to the criterion of each researcher or group of researchers (8-9).

The seismic risk map in Spain (10) and similar maps of many comparable countries (11) are based on demarcating such zones (figure 2). The method works from the assumption that no significant earthquake can occur outside them, while, within them, earthquakes may be generated in any site. This simplification skates over the fine detail of the distribution of earthquakes in space. As a result, the risk is in general overestimated, since some areas within a seismic zone do not generate earthquakes even if we assume the contrary (12). Conversely, the earthquake risk may be underestimated in some one-off areas where earthquakes have occurred, since the risk is averaged out with the lower risk of inactive areas roundabout. In general the distribution of earthquakes (figure 1) is more complex than these zones may suggest (figure 2), and many do not occur within them.

This article draws up a map showing where future earthquakes are most likely to occur on the Iberian Peninsula, the Balearic Islands and the Canary Islands. This involves the use of a groundbreaking forecasting method (13), which estimates how far future earthquakes are likely to occur from previous ones. First of all an analysis is made of the quality of the figures to hand, selecting only the most complete and trustworthy data. An explanation is then given of the forecasting method and it is tested on a backdated basis against earthquakes that occurred between January 1985 and April 2009. It is found that most of them did indeed occur in regions demarcated by previous earthquakes, and it would have been possible to forecast a prefixed percentage of them, namely 90%. In view of the success of the backdated test, a forecast map is drawn up showing the regions where most (ideally about 90%) earthquakes are expected to occur as from May 2009.

*The distribution of earthquakes in space is very complex but not random; they tend to recur close to previous earthquake sites*

**Data Quality Analysis**

A description is now given of the figures used in this article and their quality is analysed, in the interests of selecting only the most trustworthy data. The map drawn up here is based exclusively on the location of past earthquakes. The region’s most complete earthquake list will be used, as drawn up by the Instituto Geográfico Nacional (IGN). This information is published and made freely available on the internet (14).

Only some of the region’s earthquakes can be detected. There is a bias towards the biggest quakes and those that occurred near working seismographs. Many of the small or distant earthquakes are not detected. This fact can be gauged by means of the dimension called the “magnitude of completeness”. This marks the watershed of complete detection in any given area, all earthquakes with an equal or greater magnitude being detected but not all of the earthquakes below the magnitude of completeness.
This factor has to be taken into account when making any statistical analysis of earthquakes (1), to ensure that our forecasts and the assessment of them are correct (15). If we fail to bear in mind data quality, for example, we might be misled into thinking that earthquakes occurred a long way from each other in a given region, when it might in fact be the case that only a minority of the earthquakes occurring in that region were detected. This would distort our measurements of the inter-earthquake distances. Likewise, the actual percentage of forecast earthquakes can be calculated only if it is reasonably sure that all earthquakes in that region within the considered magnitude frame were detected. It is therefore necessary to consider only earthquakes with a magnitude equal to or greater than the magnitude of completeness. Smaller magnitude quakes also input information, but they should not be included in the final analysis.

It is not yet possible to ascertain exactly where the next earthquake will occur, since their generation is a very complex process and impossible to observe directly.

The IGN-run National Seismic Network (Red Sísmica Nacional) comprises a set of stations fitted with seismographs distributed throughout the whole of Spain. This network’s figures are the IGN’s main source of information for pinpointing the earthquakes and drawing up the list used herein. This network has been regularly upgraded over time (16-18). The period of highest data quality began in 1985, by which time there were many seismic stations enabling earthquakes to be located in real time. As from 1991 data began to be used from a very sensitive device, made up by a group of seismographs set up around Sonseca, Toledo (18-19). In 2000 wideband digital seismographs began to be installed, allowing more sensitive recording of soil movements (18). On 2 June 2003 the IGN began to use an improved method for calculating earthquake magnitudes (20). Due to this improvement the magnitudes of events occurring before and after this date are not strictly comparable.

This article draws up a map showing where future earthquakes are most likely to occur on the Iberian Peninsula, the Balearic Islands and the Canary Islands.

A measurement has been made of the IGN database’s magnitude of completeness for four different periods, marked off by the abovementioned developments in the Red Sísmica Nacional. This magnitude has been mapped by means of the «entire magnitude range» method (21). There follow some technical details for specialist readers. The mesh used had sampling points at every 0.1° of longitude and latitude. A calculation of the magnitude of completeness is made for each point using the 60 earthquakes closest thereto, providing that the furthest is at most 100 kilometres away. The result is an average of 200 re-samplings (bootstraps) per point and calculations are made using the ZMAP computer programme (22).

Figure 3 shows the magnitude-of-completeness maps, illustrating how this magnitude has steadily come down over time. Progressive improvements in the Red Sísmica Nacional have made the figures increasingly comprehensive. The sharp drop in the final period could be partly an effect of the new method used to calculate the magnitudes. The lowest figures are recorded on
On 29 January 2005 an earthquake with a magnitude of 4.6 on the Richter Scale was recorded, with epicentre in the parishes of Zarzella de Ramos and La Paca in the Murcia municipality of Lorca.

It has been decided to consider only the earthquakes occurring within the two polygons taking in the regions with the most complete figures. In these regions, moreover, the earthquakes should be located with greater precision. One polygon includes the Iberian Peninsula, Balearics and neighbouring maritime areas. The other does likewise with the Canary Isles. Table 1 lists the coordinates of the polygon vertices to facilitate future comparisons of the results. Table 2 shows the minimum values used as from the specified dates, so that the data are reasonably complete within each polygon.

**Description of the Forecasting Method**

The method used herein has been recently proposed and tested against figures from around the world and from several regions of California (13). It serves for forecasting in which regions most earthquakes will occur without giving information on the exact site, the exact time or the magnitude they will have. As in other related methods (4-6), it involves drawing circles around the epicentres of previous earthquakes and assuming that future earthquakes will tend to occur within them. The new feature of the method used here (13) is the choice of this radius on the basis of inter-earthquake distances, thus giving this radius a physical significance. The basic hypothesis is that the distribution of distances separating previous earthquakes can be extrapolated to ascertain the distance therefrom that the next earthquake is most likely to occur. The main practical improvements of this method as compared with earlier procedures (4-6) are twofold: firstly it forecasts a pre-fixed percentage of earthquakes and secondly the maps produced are fine tuned over time (13).

![The map involves drawing circles around the epicentres of previous earthquakes and assuming that future earthquakes will tend to occur within them](image)

This forecast is binary in type: the next earthquake is expected to occur in marked zones of the map and is not expected outside them. There is no grey area between these two extremes. If the next earthquake occurs within the marked zones the forecast is considered to have been right, and wrong otherwise. The aim is to predict the greatest number of earthquakes marking the smallest possible area within the region under study. Binary forecasts are frequently used in weather forecasting with statements such as: «tomorrow it will rain (or will not rain) in this city». The sheer simplicity of this utterance means that a thoroughgoing statistical assessment can be made (3, 24).

The method can be explained in detail without needing to use any formula, with the following instructions (13):

- A study region is chosen together with a forecasting start date. Only the earthquakes occurring in this region will be considered, as from this date, with a magnitude equal to or greater than the magnitude of completeness at each moment.
- The percentage of earthquakes to be predicted is fixed beforehand. The higher this percentage, the larger must be
the areas marked on the map. The percentage 90% has been chosen for this article.

- Initially no data is to hand on where the next earthquakes will occur, so the whole region is marked. The first two earthquakes will thus be speculatively «forecast».
- When two or more earthquakes have occurred, the following is done just after each one:
  - Check whether the earthquake occurred where expected and calculate the percentage of earthquakes forecast.
  - Measure the distance from each epicentre to its nearest «neighbour».
  - Choose the 90 percentile from among these distances: the distance such that 90% of all of them will be less than or equal thereto.
  - Draw a circle around each one of the epicentres of the earthquakes that have already occurred, taking the above-calculated distance as the radius. On a precaution principle, if less than 90% of the earthquakes have been forecast, the new radius is not allowed to be less than the former.

The resulting map is hence tested against each earthquake and modified afterwards: a new circle is added around its epicentre and generally the radii of all circles are changed. The more earthquakes that have occurred in any region, the denser will be their distribution. The distances between them therefore fall and the same usually goes for the selected radius. As a result, as shown in the following section, the areas marked tend to become smaller: the map, therefore, is fine tuned automatically and naturally.

On 2 February 1999 two earthquakes were recorded in the Murcia locality of Puebla de Mula, with magnitudes of 3.5 and 5.2 on the Richter Scale.
Figure 4. Aspect the forecast maps would have shown if drawn up just before the two higher magnitude earthquakes recorded in the period under study. The blue circles are drawn around previous epicentres, showing the regions where the next earthquake was expected to occur with 90% probability. Both events would have occurred within these regions, very close to the southern border of the study polygon.

The evolution of the forecast over time is shown in figure 5. The lefthand table shows the area marked by the circles. Initially this is high and see-sawing but soon begins to settle down and shrink. The percentage of forecast earthquakes (regardless of their magnitude) is shown in the righthand table. After the initial oscillations it holds perfectly steady at the target 90%, thus bearing out the method’s working hypothesis. The result also implies that the method optimises the area marked at each moment, automatically fine tuning it to forecast the target percentage of all the earthquakes. The success percentage is considerably higher than that of the marked area, statistically bearing out the procedure’s predictive capacity. Furthermore, with continued forecasting of the same earthquake percentage but marking an ever smaller area, the map’s performance progressively improves.

Figure 6 shows the magnitude-related percentage of forecast earthquakes. The method forecasts about 90% of the earthquakes, regardless of their magnitude. The slight difference for earthquakes of magnitude five or higher is not statistically significant, since there are only thirteen events (eleven of which, 84.6%, would have been predicted).

Figure 5. Results of the backdated forecast, from January 1985 to April 2009. Lefthand table: area occupied by circles on the forecast maps. As more earthquakes occur, more circles are added to the map, while their radius tends to shrink. With time the marked regions tend to take up a smaller area, so the map becomes increasingly fine tuned. Righthand table: percentage of earthquakes forecast. The target 90% is actually borne out on the graph.

The final map, updated as at 30 April 2009, is shown in figure 7. In the Iberian region the circles have a 10.9 kilometre radius, taking up 30.9% of the polygon area. In the Canary region they have a 13.7 kilometre radius and take up 45.5% of the polygon area. Adding together the areas of the two polygons, we come up with a total area occupied by the circles, which comes out as
Conclusions

This article shows that it is possible to forecast where future earthquakes will break out on the Iberian Peninsula, Balearic Isles and Canary Isles simply on the basis of where previous earthquakes have occurred. This study, as in other regions where the same method has been used (13), shows that, by marking a relatively small area in the region under study, a forecast can be made of a pre-fixed percentage of quakes (figure 5), regardless of their size (figure 6).

The resulting map is more complex and detailed (figure 7) than that of the officially considered seismic zones (figure 2). It also shows that, outside these zones, there are many sites proven here to be capable of generating future earthquakes. This research suggests that, to estimate the seismic risk, it might well be worthwhile to consider in more detail exactly where previous quakes have occurred, calculating the higher risk for these particular areas. At least one work along these lines has been published for the Iberian Peninsula (25).

With time the marked regions tend to take up a smaller area, so the map becomes increasingly fine tuned

These results also bear out the importance of detecting and pinpointing as many lower-magnitude earthquakes as possible (26). This would allow us to fine tune future forecast maps. Inside the Iberian Peninsula and on the Canary Islands the figures are complete down to small magnitudes (figure 3). This is not the case in the outlying parts of the peninsula, precisely where large magnitude quakes are most frequent, e.g., the two biggest events of all those studied herein (figure 4) or the great Lisbon earthquake of 1755, which began in the southwest of the Iberian Peninsula and caused grave damage in Portugal and Spain (27). It would therefore be worthwhile to make further investments in improving and extending the seismic networks to be able to pinpoint more earthquakes with greater precision.

The main limitation of the map as drawn up herein (figure 7) is that it will not be updated with new earthquakes after it has been published on 15 May 2009. This differs from the trial carried out with figures ranging from 1 January 1985 to 30 April 2009, in which the map was updated after each new event. To ensure that the map remains effective as future earthquakes occur, the percentage of earthquakes occurring within the marked regions (ideally about 90%) should be considerably greater than the percentage area that these regions occupy (32.4%). This will have to be tested later as it is always possible that big quakes might occur in sites with few previous events (28). Only time will tell, therefore, whether the map published here continues to show the same effectiveness as the living version of the backdated trial.

On 15 June 1964 a medium intensity earthquake hit the province of Granada, causing damage to housing in several localities.
Figure 7. Location forecast map of future earthquakes in the Iberian Peninsula, the Balearic Islands and Canary Islands. The borders of the Spanish provinces have been sketched in as reference. Ideally, about 90% of the epicentres of earthquakes occurring from May 2009 onwards (with a magnitude equal to or greater than 2.5 in the Iberian polygon and 2.2 in the Canaries) should fall within the areas marked in dark blue.

Acknowledgements

We would like to thank the members of the PSE-ARFRISOL consortium for their collaboration. PSE-ARFRISOL, Reference PS-120000-2005-1, is a singular scientific-technological project of a strategic character accepted by the National R&D Plan 2004-2007, co-financed by ERDF and subsidised initially by the Ministerio de Educación y Ciencia (MEC) and now by the Ministerio de Ciencia e Investigación (MICINN).

By way of a glossary

**Epicentre.** Point of the earth’s surface under which, at a certain depth, an earthquake commenced.

**Fault.** An irregular fracture caused by the movement of one block of rock against another. It might be microscopic in size but can then grow in time until becoming kilometres long in extreme cases. Fault movements tend to be episodic rather than continuous. The blocks slowly warp without movement until building up sufficient tension to overcome mutual friction. The relative movement is then sudden, unleashing an earthquake. This process is usually repeated cyclically. The bigger the fault, the bigger the resulting earthquake is likely to be.

**Magnitude.** A measurement of the energy released by an earthquake. Each magnitude increment entails a 32-fold increase in energy. The biggest magnitude ever recorded was 9.5 in the Great Chilean Earthquake of 1960. In Spain damage is usually produced in vulnerable buildings by earthquakes with a magnitude of 4 or 5 or greater. Ceteris paribus, an earthquake’s effects are directly proportional to its depth of origin.

**Seismometer.** An instrument that measures and records soil movements, such as earthquake vibrations. Analysis of these movements in several seismometers enables any earthquake’s origin and magnitude to be determined.

**Earthquake.** Land vibration usually caused by the sudden movement of one block of rock against another along the surface.
of a fault. This movement, which may last for several minutes, starts in a specific point of the fault, over which the earthquake epicentre lies.

**Bibliography**


4. Kafka, AL; Levin, SZ. Does the spatial distribution of smaller earthquakes delineate areas where larger earthquakes are likely to occur? Bulletin of the Seismological Society of America, 2000, (90) 724–738.

5. Kafka, AL. Statistical analysis of the hypothesis that seismicity delineates areas where future large earthquakes are likely to occur in the central and eastern United States. Seismological Research Letters, 2002 (73), 992–1003.


Figure 6. Percentage of earthquakes forecast in the backdated trial for different magnitudes. The results of the study zones (Mainland and Balearics, and Canaries) have been jointly considered. The method would have forecast about 90% of the earthquakes, regardless of their magnitude.