PROJECT MARNA NATURAL GAMMA RADIATION MAP

E. SUÁREZ - J.A. FERNÁNDEZ

PROJECT MARNA CONCEPTION

The confusion created by the accident that occurred in one of the Chernobyl reactors in April of 1986 made the general public and governments aware of the need for improved monitoring of environmental radiation levels. The levels of total gamma radiation or total gamma exposure rate over large areas reached values as high as 400 microRoentgen/hour (μR/h) and at points exceeded 1000 μR/h. Figure I shows the distribution of exposure rate levels (μR/h) primarily due to Cesium 137 (Figure II) in Sweden in the days following the accident. It should be borne in mind that, depending on the type of geological formations, normal values range from 5 to 30 μR/h.

In November of 1986, the IAEA held a meeting of consultants to discuss the possible contribution of organizations specialized in uranium prospecting to knowledge about natural radiation, and to increase emergency response effectiveness in the event of a nuclear accident. The group of consultants recommended that the IAEA publish a description of the Swedish response to the emergency for two reasons: first, so that the actions of the Swedish Geological Institute could serve as an example of the contribution that expert personnel trained in uranium prospecting could make; and second, so that the rapid, fluid communication between the Swedish Geological Institute and Radiological Protection Authorities and the Armed Forces could serve as an example.

In addition, the IAEA recommended to all countries that natural gamma radiation maps be made available to evaluate the levels of natural gamma radiation and possible increases, and it also indicated its concern that information be standardized. In addition, it stressed the advisability of using data obtained from uranium prospecting.

The European Community also began a pilot study in November 1986, which demonstrated that there were no insurmountable technical problems involved in producing an atlas of natural radiation levels. Figure III shows the first atlas that was published in 1993 in the "Radiological Atlas. Sources of Ionizing Radiation in Europe", prepared for the Directorate of Environment, Nuclear Safety and Civil Protection of the ECs. Figure IV shows the map of the United Kingdom, and Figure V shows the map of exposure rates in the former Federal Republic of Germany published by the Institut für Angewante Geodasia.

It should be noted that to evaluate the effects of contamination from Chernobyl, Sweden used the same type, configuration and geometry of aerial detection equipment as those used in Spain between 1979 and 1981 by the former Junta de Energía Nuclear and by the Empresa Nacional del Uranio in the successive National Uranium Prospecting Plans. The same methodology was also used, the only difference being the depth of the gamma spectrometer windows; instead of using the potassium-40, uranium and thorium windows that are used in radioactive mineral prospecting, the main windows used were the Cs 137 and those of other elements that cause radioactive contamination.

The Junta de Energía Nuclear (and the Empresa Nacional del Uranio) carried out successive aerial radioactive material prospecting campaigns in Spain during the period 1968-1980. These campaigns provided very good measurements of total gamma radiation and

F I *and* **F II**

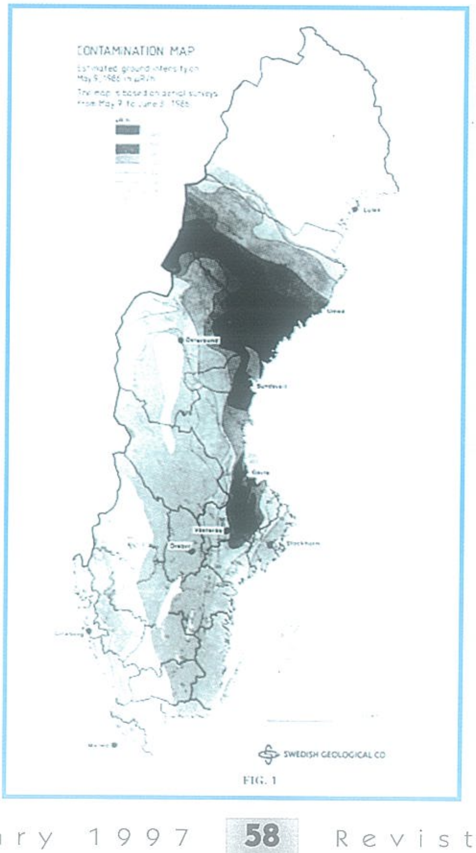


FIG. 1

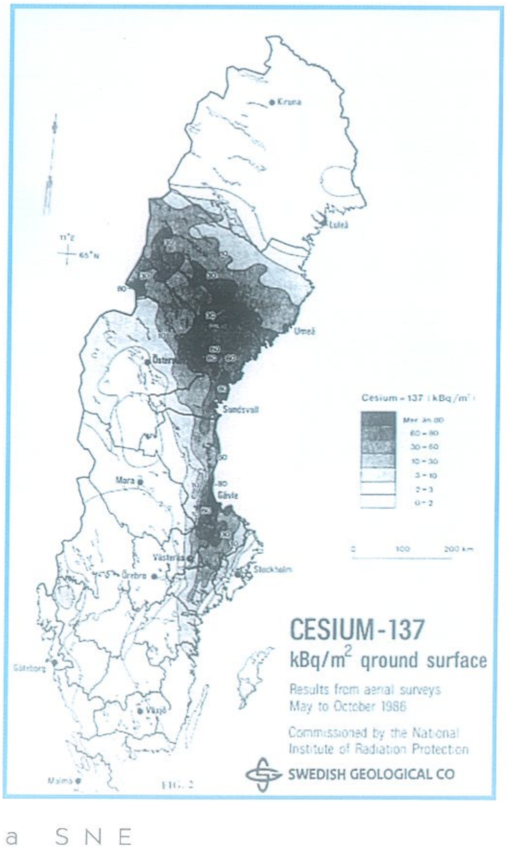
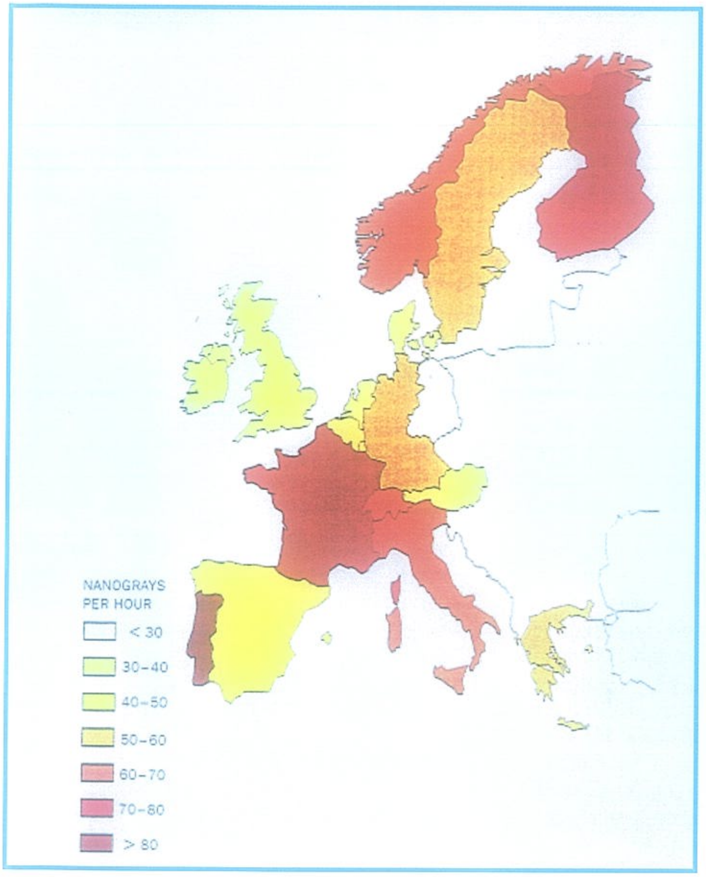
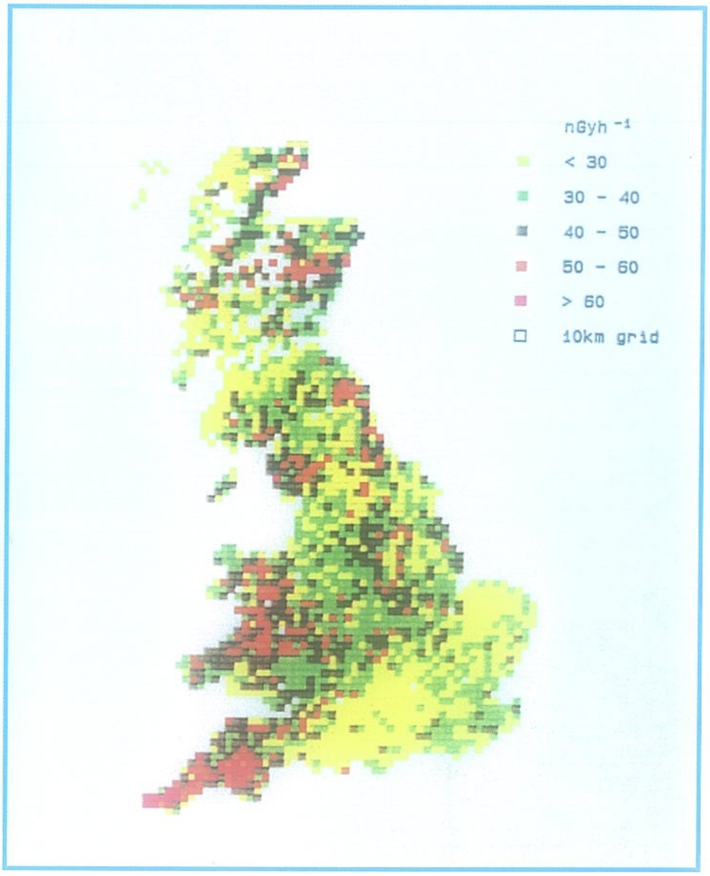


FIG. 2

F III *and* **F IV**





gamma spectometry. Aerial data were acquired that covered approximately 60% of the peninsular area, and they were obtained primarily by using the U.S. methodology that, together with the Canadian methodology, was the most advanced at that time. In addition to information on aerial prospecting, numerous ground measurements of a good part of Spain were also obtained. Figures VI and VII show the location of the zones covered by each of these methods. Good basic information was therefore available to begin an evaluation project of natural gamma radiation in Spain.

With contacts established between the Consejo de Seguridad Nuclear and the Empresa Nacional del Uranio, S.A., a mixed technical team studied the possible use of data from successive uranium research plans in drawing up a natural exposure rate map that would account for international recommendations regarding production of natural radiation maps. The conclusions of the work group were translated into a project proposal that addressed the cost, scheduling and methodology to be followed to prepare pilot maps of natural radiation.

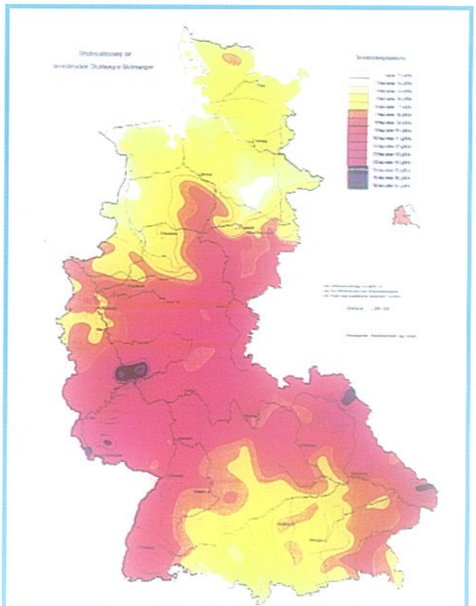
NATURAL RADIATION

Natural radiation is the most important source of radiation to which the general public is exposed. Natural radiation comes from external and internal sources.

The external sources are due to the following:

- the presence of natural radioactive elements that are found in the ground, construction materials, water and air.
- the existence of cosmic radiation.
- the formation of cosmogenic radionuclides that are produced by the interaction of cosmic radiation with atoms present in the atmosphere. The most important is carbon-14.

F V



Internal sources correspond to natural radioactive elements, mainly postassium-40 and carbon-14, which are involved in the composition of tissue and in physiological processes in live organisms.

Project MARNA deals only with external sources of gamma radiation, excluding radon gas and cosmogenic radiation, although the value of the latter has been estimated for our latitudes.

There are several types of natural radiation:

- *alpha particles.* These are helium nuclei with a low power of penetration. They are only capable of passing through a few centimeters of air and are absorbed by the skin.
- *beta particles.* These are electrons capable of passing through approximately one meter of air. They are absorbed by some 2 cm. of water or biological tissue.
- *gamma radiation* emitted by radioactive ground elements, with a penetration power of some 200 meters of air and some 40 cm. of ground.
- *cosmic radiation.* It has a high power of penetration and is capable of passing through the earth's atmoshpere and reaching the ground.

Gamma radiation emitted by rocks is due to the presence of the following elements:

potassium, thorium and uranium. There are also other natural radioactive elements such as rubidium 87, samarium 148 and lutetium 171, but they are found in such small proportions that their contribution to total gamma radiation is negligible. The significant energy peaks of the gamma spectrum that are used to measure natural radioelements are: 1.46 MeV corresponding to potassium-40, which is used to determine the content in natural potassium; 1.1204 and 1.764 MeV corresponding to bismuth 214, a descendant of natural uranium, which are used to estimate the content in uranium; and 2.62 MeV corresponding to thallium 208, a descendant of natural thorium, that is used to determine the content in natural thorium.

Table I shows the average contents and range of variation of potassium, thorium and uranium in igneous and sedimentary rock.

Chemical potassium contains 0.0119% of potassium-40 (Adams J.A.S. and Colbs, "Physics and Chemistry of the Earth", Pergamon Press).

As regards the average terrestrial contribution of each of these to natural gamma radiation, 45% comes from potassium, 45% from thorium and 10% from natural uranium.

A 1% potassium concentration produces an exposure rate of 1.505 μR/h, whereas 1 ppm of thorium results in 0.310 μR/h and finally 1 ppm of uranium in 0.625 μR/h.

Of the thre elements mentioned above, uranium is the most difficult to measure since bismuth 214 is produced from radon gas (Radon-222), which has an average lifetime of 3.5 days, leaks from the ground and can become concentrated in the air and attach to dust and aerosols. The radon concentration varies depending on atmospheric conditions and follows the laws of gas diffusion. Maximum concentrations have been measured under conditions of atmospheric inversion. The content fluctuates between maximums that are usually measured in the early hours of the day and minimums that are measured towards midday and early afternoon. Rain decreases the radon content in the air.

As regards cosmic radiation, primary cosmic radiation is primarily composed of high-energy protons that interact with atomic nuclei to produce electromagnetic radiation and secondary cosmic radiation. Its intensity varies by latitude and altitude and is relatively constant wherever it varies more or less 5% according to solar cycle phases. Its intensity approximately doubles every 2000 meters of altitude, and its energy exceeds 3 MeV. At our latitudes, exposure due to cosmic radiation is some 4-5 μR/h.

During commercial airplane trips, 30 times more radiation is received than at ground level.

TI

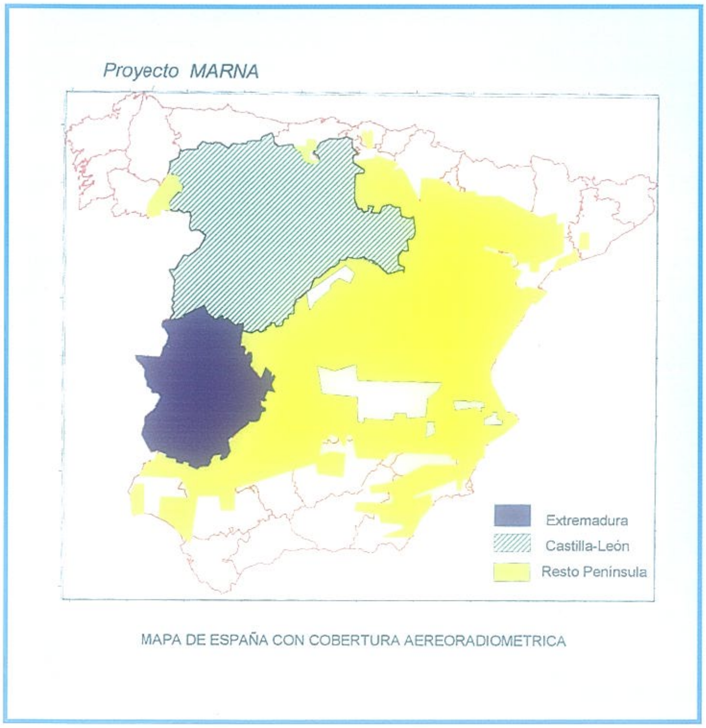
Contents of Potassium, Thorium and Uranium in Igneous and Sedimentary Rocks

	Potassium (%)	Thorium (ppm)	Uranium (ppm)
Basaltic Rock			
Average value	0.8	4.0	1.0
Range	0.2 - 2.0	0.5 - 10.0	0.2 - 4.0
Granitic Rock			
Average value	3.0	12.0	3.0
Range	2.0 - 6.0	1.0 - 25.0	1.0 - 7.0
Argillaceous Rock			
Average value	2.7	12.0	3.7
Range	1.6 - 4.2	8.0 - 18.0	1.5 - 5.5
Sandstones			
Average value	1.1	1.7	0.5
Range	0.7 - 3.8	0.7 - 2.0	0.2 - 0.6
Carbonated rock			
Average value	0.3	1.7	2.2
Range	0.0 - 2.0	0.1 - 7.0	0.1 - 9.0

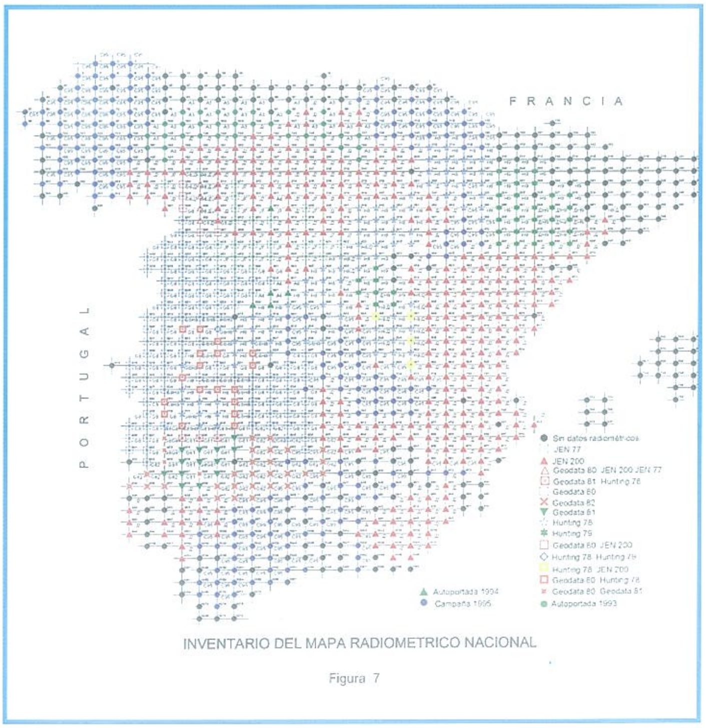
MEASUREMENT UNITS

Radiation intensity in one place is called exposure or exposure rate (E), measured in Roentgens (R). A Roentgen is defined as the amount of X or gamma radiation that one electrostatic charge unit of any sign produces in one ml of air at standard pressure and temperature.

F VI - *Map of Spain with Aeroradiometric Coverage*



F VII - *Inventory of the National Radiometric Map*



Starting in 1956, a new unit was used that was applied to any form of ionizing radiation; this unit is called absorbed dose (A) and its unit is the rad, which is the deposition of 100 ergs of energy per gram in an absorbent material. In ambient radiation measurements, both units - the Roentgen and the rad, corresponding to exposure rate and absorbed dose in the air respectively - were used indifferently. The ratio between the two is as follows:

$$A = a\,E \qquad \text{where } a = 0.869 \text{ rad.}$$

For medical or human health purposes, the most important absorbent medium is the human body. In 1978, O'Brien calculated the conversion factor between exposure rate and whole body dose measured in rads, which is given by the formula $A = 0.6\,E$.

As different types of radiation cause different effects on biological tissue, another unit was defined: the REM, which are the initials of Roentgen Equivalent Man. A REM is the dose produced by any type of radiation that causes biological effects on a man equivalent to one rad of X-ray. The dose in REMs is the product of the dose in rads by a quality factor that depends on the Relative Biological Effectiveness, RBE, of the radiation being considered.

Nowadays, for purposes of Radiological Protection, two units of the International System are used: the Sievert (equivalent dose) and the Gray (absorbed dose).

The Sievert is the unit of equivalent dose corresponding to a REM, and its ratio is given by the formula 1 Sv = 100 REM.

The *equivalent dose* is the product of the absorbed dose (D) by the quality factor (Q) and the product of the other modifying factors (N) that account for the radiation characteristics and radionuclide distribution. It is usually considered that N=1. When the word dose is used, it always refers to equivalent dose.

Absorbed dose is the coefficient de by dm, where de is the average energy transferred by the radiation to the matter in an element of volume, and dm is the mass of matter contained in this volume. $D = d\varepsilon/dm$. The unit of absorbed dose is the Gray.

The Gray is the unit of absorbed dose corresponding to the rad, and it is the energy conveyed by ionizing radiation to material corresponding to one joule per kilogram. The ratio between the former absorbed dose unit (rad) and the new Gray unit is given by: 1 Gy = 100 rads = 1 J. Kg -1.

The results of Project MARNA refer to the gamma exposure rate and are expressed in R/h. On the basis of these results, the absorbed dose and whole body dose can be immediately calculated.

Tables II and III, taken from ICRP-39, provide comparative information on human exposure and dose due to natural radiation sources. As for the contribution of each of the natural radionuclides to absorbed dose, the following equivalencies have been calculated:

1% potassium = 0.01310 micrograys/hour
1 ppm of thorium in equilibrium = 0.00269 "
1 ppm of uranium in equilibrium = 0.00543 "

T II

Estimate of the Annual Equivalent Effective Dose From Natural Radiation Sources in Areas of "Normal" Background

	Annual Equivalent Effective Dose (millisievert)		
Source	External Irradiation	Internal Irradiation	Total
Cosmic Radiation			
Ionizing Component	0.28		0.28
Neutronic Component	2.02		0.02
Cosmogenic Nuclides		0.015	0.015
Primary Nuclides			
Potassium-40	0.12	0.18	0.30
Rubidium-87		0.006	0.006
Uranium. U-238 Series	0.009	0.95	1.04
Thorium. Th-232 Series	0.14	0.19	0.33
Total (rounded off)	0.65	1.34	2.0

OBJECTIVES OF PROJECT MARNA

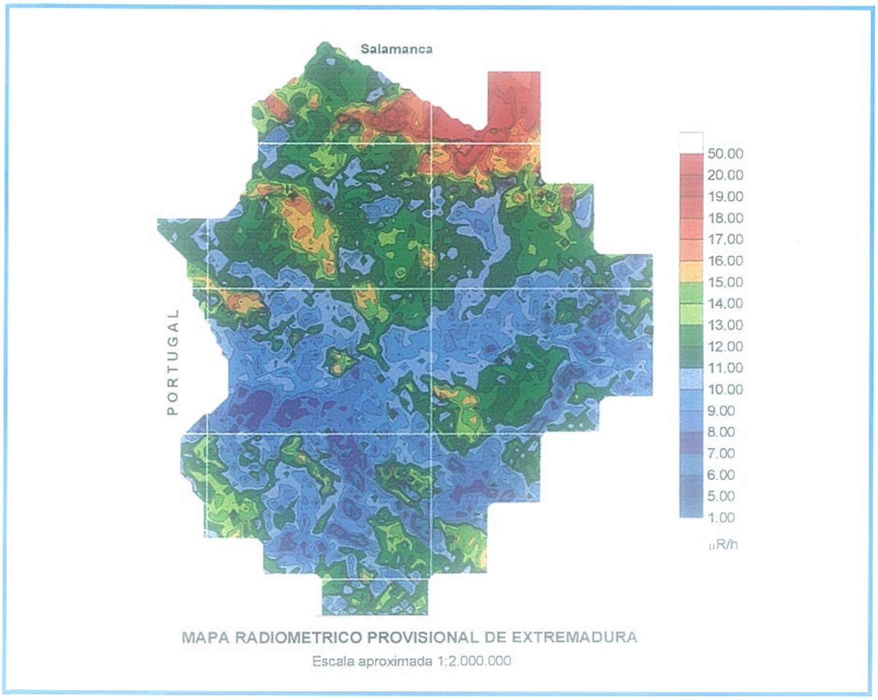
In December 1991, the Consejo de Seguridad Nuclear and the Empresa Nacional de Uranio S.A. signed an Agreement to undertake the MARNA (Natural Radiation Map) Project with the following objectives:

- Obtain natural gamma radiation maps from 4 sheets of the national topographic map to scale 1:50,000 that indicated a high level of natural radiation. The selected sheets were 475, 476, 525 and 623, corresponding to Lumbrales, Villavieja de Yeltes, Ciudad Rodrigo and Malpartida de Plasencia.
- Obtain two maps to scale 1:200,000 of two Autonomous Regions. Extremadura and Castilla-León were chosen, in all some 130,000 square kilometers.
- Obtain a map of natural radiation to scale 1:1,000,000.

The technical project lasted for four years.

The project objectives were ambitious, and achieving them was contingent on being able to determine the exposure rate estimation at the reasonable cost provided for in the project and, therefore, on being able to use existing information on aerial radiometry and establish good correlations between measurements obtained by different equipment, and also between ground and air measurements, since obtaining new data through intensive field work obviously exceeded the economic project provisions and would extend project duration.

F VIII - *Provisional Radiometric Map of Extremadura. Approx. Scale: 1:2,000,000*



T III

Estimate of Human Exposure Due to Natural Radiation Sources

	A.M.E.E.D. (mSv)*	Fraction of Total (%)	Dose Range**	Control Facility
Extraterrestrial				
External Exp.	0.3	15	medium	no***
Internal Exp.	0.01	0.5	narrow	no
Terrestrial				
External Exp.				
Outdoor	0.06	3	medium	no***
Indoor	0.29	14	wide	si
Internal Exp.				
- K-40 & Rb-87	0.19	9	narrow	no
- U-238 Series				
Outdoor inhal.	0.06	3	medium	no
Indoor inhal.	0.77	38	very wide	si
Ingestion	0.14	7	medium	si
- Th-232 Series				
Outdoor inhal.	0.03	1.5	unknown	no
Indoor	0.17	9.0	wide	no
Ingestion	0.02	1	medium	si

** A.M.E.E.D. Annual mean equivalent effective dose.*
*** Very wide means a variation factor of the order of 1000 between extremes; wide, a variation factor of the order of 100; medium, of the order of 10; and narrow, of the order of 5 or less.*
**** Reduction of this type of exposure means geographic mobility. This may be possible but is often unfeasible. Avoiding new situations usually causes fewer problems.*

Practically the whole first year of project development was devoted to selecting data files and establishing the detailed methodology for calculating the correlations between the different measurements obtained by different equipment.

DATA BANK AVAILABLE FOR THE PROJECT

The available radiometric data come from uranium deposit prospecting campaigns undertakn up to 1980 by the former Junta de Energía Nuclear and subsequently by ENUSA. In all, they include information on more than 30 years of radioactive mineral prospecting. Terrestrial and aerial measurements covering the surface area shown in Figure VI are available.

Terrestrial measurements. These include data from regional and general prospecting campaigns carried out on grids covering between 200 and 1000 m., and detailed prospecting carried out on grids covering between 200 and 5 m. and, in some cases, less. The measurements correspond to exposure rate and are expressed in microroentgen/hour, and in other cases in counts/second. There are also numerous geologic-radiometric evaluation reports on anomaly and/or deposit zones. There is also detailed information on the characteristics of the equipment used for measuring.

In addition to these measurements, there are measurements from self-supporting radiometric prospections in which the measuring equipment was installed on jeeps that took measurements on passable roads, obtaining a continuous record of measurements in different types of counts/second or else mR/h. There is also detailed information on the characteristics of the equipment used for measuring.

All terrestrial measurements covered the gamma energy band between 0.4 and 2.7 MeV, which is the one normally used to measure natural radionuclides.

Aerial measurements. These include total radiation measurements and spectrometric measurements.

Total radiation measurements. The first aerial measurements were obtained starting in 1968 and ending in 1975. To obtain these data, total count detectors were used that covered the gamma energy band between 0.4 and 2.7 MeV. Flights were made at an altitude of less than 120 m, and the records were obtained in a continuous band and were corrected by flight altitude to reduce them to a standard altitude of 70 m. These were flights made according to flight paths separated by 600 to 1000 meters and that covered an area of some 200,000 square km. The measurements are in counts/second and refer to specific equipment, the characteristics of which are still kept. The equipment used were the Saphimo SRAT SPAT-2 and SPAT-3. Maps were drawn up for total counts and the measurements are corrected by flight altitude.

Spectrometric measurements. These were obtained starting in 1979. Multichannel spectrometers with 256 and 512 channels were used to cover the gamma radiation energy band between 0.4 and 2.7 MeV. They obtained total radiation measurements expressed in counts per second: equivalent potassium (en % potassium), equivalent thorium (ppm of thorium) and equivalent uranium (ppm of uranium). The measurements are corrected and standardized by flight altitude, system background, cosmic radiation and interchannel contribution (dispersion from Compton effect). The corresponding maps of distribution of each element are at scale 1:50,000. The equipment used were Geometrics Exploranium DiGRS and Geodata int, Lama4.

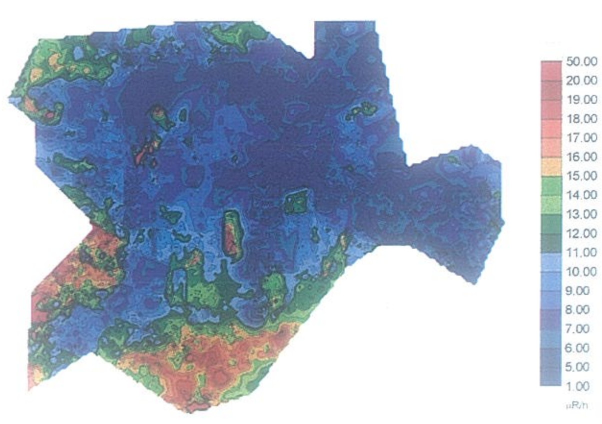
WORK METHODOLOGY

The main issues and problems that were considered in project design were as follows:

- *Representativity of aerial measurements.* It is obvious that the exposure rate measured at a point above the ground does not coincide with the one obtained at 100 meters above that, since the first is from the point and the second includes radiation from a circle with a radius two times the flight altitude. It was considered that the latter measurement is the most representative one of the surroundings. In other words, if a persons stands still the terrestrial measurement would be exact, but as this is not the case because a person moves around his/her surroundings, the aerial measurement is more representative. On the other hand, the cost of a map based on point measurements was prohibitive and required many more measurements to achieve the representativity of an aeroradiometric map.

- *Selection of methodology.* This involved the following alternatives: a) use total radiation measurements, or b) start with the information in the maps to scale 1:50,000 on

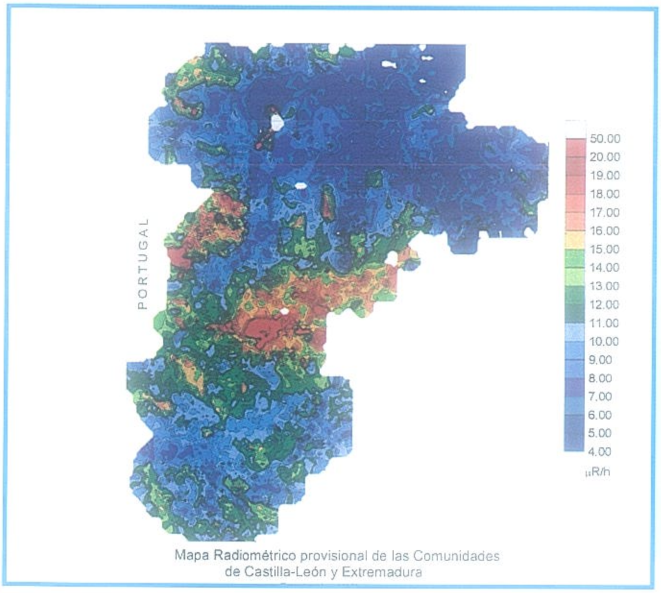
F IX - *Provisional Radiometric Map of Castilla-Leon. Approx. Scale: 1:3,000,000*



MAPA RADIOMETRICO PROVISIONAL DE CASTILLA-LEON

Escala aproximada 1:3.000.000

F X - *Provisional Radiometric Map of the Castilla-Leon and Extremadura Regions (Resolution 1/16).*



potassium, uranium and thorium contents produced during the aerial radioactive mineral prospection. The first method a) was chosen because it provided total radiation data on approximately 75% of the peninsular area - some from terrestrial prospecting and others from aerial prospecting - the cost was significantly lower (some eight times less), and finally becaues the estimate of errors over total average radiometry for a unit area of one square km. was acceptable. The second alternative b) was rejected for several reasons: first, because the incertitudes stemming from the way to calibrate the equipment in the calibration slabs did not guarantee that the final information on exposure rate would be more exact than the information from total radiation. The calculation method assumed that the gamma spectrum is measured under calibration conditions. If radioelement distribution varies a lot in the geological formations in the area "seen by the plane", significant errors can occur in estimation of the different radioelements. Secondly, the cost of the exposure rate map obtained by the second option was very high. Finally, information with energy discrimination was only available for 30% of the peninsular area.

- *Data Reduction*: There were more than 150,000 aerial measurements per 1:50,000 topographical sheet from the records originally available. It was a complicated, costly task to process these data, and therefore the information already provided in the radiometric maps to scale 1:50,000 was used, reducing information to one datum per square km., i.e. approximately 500 values per 1:50,000 topographical sheet.

- *Correlations between aerial measurements obtained with different measuring equipment.* To establish correlations between measurements obtained in 1980 by Geodata (cps) and in 1978 and 1979 by Hunting (cps), the flight overlap zones were used, most significantly the area of Malpartida de Plasencia where a 250 square km. overlap existed. The values coinciding with the crossover points of a square grid measuring 250 on each side were retrieved, and a linear correlation coefficient of 0.7915 was obtained. By using the average of nine points, the representative area was 0.5 square km. and the linear correlation coefficient increased to 0.902, which is obviously valid for the unit grid established for the project, which was 1 square km.

- *Correlations between terrestrial radiometry measurements obtained with different equipment.* Standard equipment used were the ES-3 apparata (microroentgen/hour) manufactured and calibrated by CIEMAT. There were also field measurements obtained by Saphimo Srat SPP-2 apparata and ES-4 apparata used by ENUSA and the former Junta de Energía Nuclear. In order to establish correlations, the range of variation of the geological background that approximately covers the interval between 2 and 50 μR/h was used. The correlation coefficients in all cases were above 0.961.

- *Correlations between aerial and terrestrial measurements.* It was initially attempted to correlate aerial and terrestrial measurements point by point and demonstrate that this correlation existed. However, the procedure was rejected due to the differing representativity of the measurements as mentioned above. It was decided to determine the correlation by means of "infinite terrestrial sources" or radiometric "plateaus", i.e. extensive areas of homogeneous radiometry, selecting different zones to cover the entire radiometric range of geological backgrounds. In all, some 7000 terrestrial measurements were taken and correlation coefficients exceeding 0.92 were obtained. The reliability limit is less than 1 μR/h for the average radiometry corresponding to 1 square km.

- *Correlations between geology and radiometry.* These have been used in zones for which very little information was available. The correlation between geological formations and radiometry is obvious to any prospector of radioactive minerals. Measurements were taken at some 2000 points to support map production, and also to serve as quality control of the exposure rate maps.

- *Data bank computerization.* To draw up maps to scale 1:200,000, all data corresponding to Project MARNA coverage were retrieved and the unit radiometric information from each 1:50,000 sheet of the national geographic map was individualized in DBASE files. The Symphony, StatGraf, Surview, Golden and Rockware programs, and the methodology adapted by the Computer Science Department of the University of Extremadura, were used for data control and map elaboration. Numeric quality controls, combined with graphic controls, were carried out. In this way, Extremadura has been represented by some 50,000 exposure rate data and Castilla-Leon by some 80,000 data, which correspond approximately to the above indicated radiometric coverage of one datum per square km.

To draw up the map to scale 1:1,000,000, mean radiometric values corresponding to a grid measuring 7 by 5 km. have been used, i.e. some 16,000 data. The representativity was very good in the Extremadura and Castilla-Leon regions, and good in the zones where information was available from aerial and terrestrial prospections. In zones where no measurements were available, an estimate was made by geological extrapolation.

All data regarding geographical coordinates were converted to standard UTM coordinates, and radiometric data to exposure rate in μR/h, in a generalized database. In zones lacking in adequate radiometric coverage, values were assigned by taking into account the geology of the zone, the radiometry of similar geological formations and the specific measurements taken during project execution to establish correlations between geology and radiometry. All these are included in an additional database.

Some of the most important problems resolved during the last year of project execution were as follows: conversion of the original data on geographical position to UTM geographical coordinates referred to zone 30; elaboration of provincial, autonomous region and peninsular maps (jointly and separately) also referred to UTM coordinates of Zone 30; and finally the integration of radiometric information from any geographical zone jointly and separately. To resolve this problem, Mr. Jesús Alegría of the CSN's Site Division has provided his invaluable assistance.

Figures VIII, IX, X and XI show the natural gamma radiation maps at reduced scale of Extremadura, Castilla-Leon, the two regions together and the map of peninsular Spain.

DATA BANK DEVELOPED DURING THE PROJECT

This includes the new data that had to be obtained in order to draw up maps to scale 1:50,000, 1:200,000 and 1:1,000,000, as required for project development. These can be summarized as follows:

- original total aerial radiometry data retrieved from maps to scale 1:50,000.

- data used to establish correlations between aerial measurements obtained by different equipment.
- standardized aerial radiometry maps.
- original terrestrial radiometry data obtained by different equipment.
- data used to establish correlations between terrestrial radiometry measurements obtained by different equipment.
- retrieval of already existing data to establish correlations between aerial and terrestrial measurements.
- data acquisition to establish correlations between radiometry and geology.
- new measurements obtained by terrestrial prospecting to cover minor zones where a sufficient data network did not exist.
- new measurements obtained by self-supporting prospecting of larger radiometric target zones (somewhat more than 4,000 linear km.).
- data acquisition in the field to establish correlations between aerial and terrestrial measurements. Some 7,000 data.

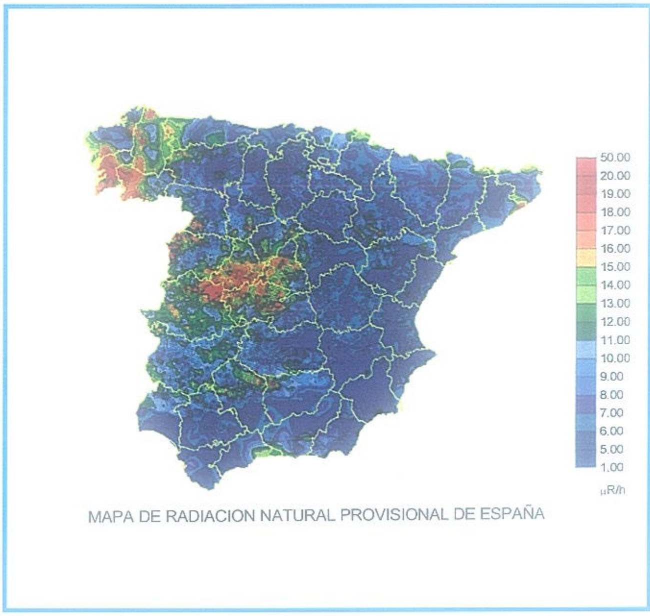
UNIVERSITY PARTICIPATION

Through specific agreements, several professors and members of the following Departments are involved in development of Project MARNA: Department of Physics of the Faculty of Veterinarian Science of the University of Extremadura, directed by Professor Antonio Baeza; Computer Science Department of the Polytechnic University, directed by Professor José Moreno del Pozo; and Department of Geology of the University of Salamanca, directed by Professor María Candelas Moro.
Collaboration with the Physics Department of the Faculty of Veterinarian Sciene of the University of Extremadura resulted in publication of the report on "Determination of the Exposure Rate Received From External Irradiation. Geological Considerations in Optimizing Sampling Schemes". This report evaluates external irradiation by means of two different techniques: the one used in Project MARNA and the one based on g emitters present in the ground in a 20,000 square km. zone with complicated geology. The results obtained have served to validate both techniques and establish criteria that, by using geology as a parameter, will help to optimize future sampling campaigns by making it possible to determine a priori the number of points to be considered and the most suitable location of these points.

PARTICIPATION IN MEETINGS OF IAEA TECHNICAL COMMITTEES

Project members have attended three meetings of IAEA Technical Committees, where they have reported on the methodology applied to development of Project MARNA. In all, four reports have been presented that refer to the use of aerial prospecting data for preparing the natural gamma radiation map of Spain.

F XI - *Provisional Natural Radiation Map of Spain.*



SPANISH-PORTUGUESE COLLABORATION

Meetings have been held with Portuguese authorities within the framework established in the "Spanish-Portuguese Protocol on Cooperation in the Nuclear Safety Domain", specifically with the Direççao Geral do Ambiente and the Instituto Geológico e Mineiro, which are the bodies in charge of elaborating the natural radiation map of Portugal. The purpose of the meetings was to exchange information on the methodology used, exchange border data and ensure that the data are consistent on both sides of the border.
The Portuguese database primarily includes measurements in c/s that were obtained by self-supporting prospection during the decades of the 50s and 60s. These data have served to elaborate maps of exposure rates in μR/h. In addition, for some zones where aerial prospecting spectrometric measurements were available, they have calculated the exposure rate on the basis of equivalent content measurements of potassium, thorium and uranium. To draw isolines, they used the SURVIEW program developed by the Canadian Geological Survey.
There is a data exchange mechanism and to date no significant discrepancies have been observed.

PROJECT MARNA-2

On December 4, 1995, a new contract was signed between the CSN and ENUSA to undertake Project MARNA-2. The project is a continuation of Project MARNA with the following basic features:

Duration: Two years.
Objectives:

1. Extend the Natural Radiation Map to scale 1:200,000 to areas outside the regions of Extremadura and Castilla-Leon, as indicated in Figure XII.
2. Update the national radiometric map to scale 1:1,000,000 with new data that have been generated.
3. Update the maps produced to scale 1:200,000 with new data that have been generated.
4. Extend the computerized databases that have served as the basis for producing maps to scale 1:200,000 and 1:1,000,000.

PROJECT MARNA APPLICATIONS

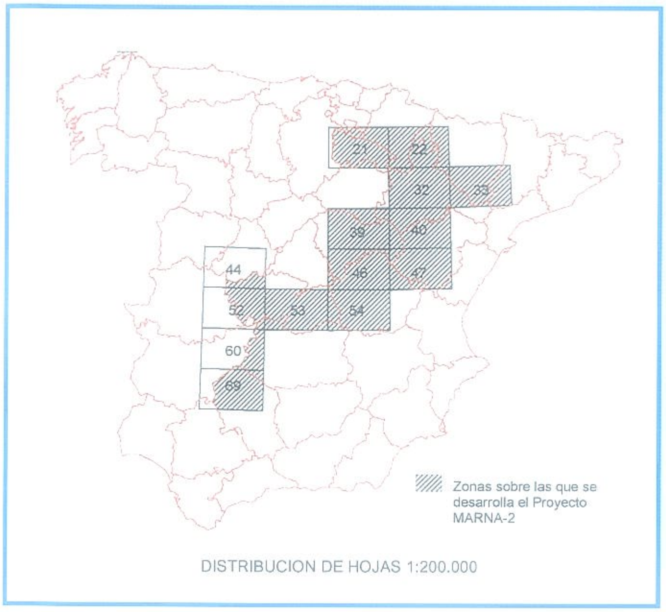
Project MARNA is a nationwide research project on the intesity of natural gamma radiation, the scope of which is consistent with other national maps, e.g. geological map, seismic danger map, ground map, tectonic map, etc. In other words, it is a basic working document, like a "photograph" of natural radiation that has immediate applications such as the following:

- Use in epidemiological studies to ascertain the effects of low radiation doses received over a long period of time.
- Evaluation and control of any increase in radiation due to natural or unnatural causes.
- Optimization of radiation measuring equipment site selection.
- Evaluation of the representativity of other radiation measurement methods.

OTHER APPLICATIONS OF PROJECT MARNA

Another possible application of Project MARNA is to use the exposure rate maps to elaborate a radon distribution map. The methodology to estimate radon content has been developed by the Canadians based on potassium-40, natural thorium and natural uranium contents in the ground measured by means of airborne gamma spectrometry.
In 1990, P. Cui, using spectrometric data obtained from aerial prospection to study the zone of Salt Lake, Utah (USA), indicated that the radon concentration in the air can be calculated by assuming that geological units present homogeneously distributed uranium and that the radon concentration that becomes

F XII



incorporated in the atmosphere can be estimated by the following formula:

$$Q = Q(Ra)\ .\ \rho\alpha\quad \lambda(Rn)\ .\ D\eta = 3.4\ .\ 10\text{-}7\ .\ Q(U).\rho\alpha\quad \lambda(Rn)\ .\ D\eta$$

where:
Q (Rn) = radon concentration in the geological unit in Ci/cm^3
Q (Ra) = radon concentration in the geological unit expressed in g/g
Q (U) = uranium concentration in the geological unit expressed in g/g
ρ = rock density in g/cm^3
α = emanation coefficient
$\lambda(Rn)$ = Radon disintegration constant in s-1
D = Diffusion coefficient in cm^2/s
η = rock porosity.

The technical team of Project MARNA is planning to carry out a pilot study on two sheets to scale 1:50,000 for which sufficient geological information exists and actual measurements of radon contents in the air are available, by applying the methodology described by the Canadians and by I.P. Cui.
In principle, one of the pilot sheets would be undertaken in the Extremadura Region and another in the Salamanca Region, where good information is available. They would be based on potassium-40 (%), thorium (ppm) and uranium (ppm) content maps obtained on the basis of aerial measurements. At the same time, an estimate would be made of the radon contents based on exposure rate (μR/h) maps and on the hypothesis that potassium and thorium are present in the ground according to the average contents corresponding to the geological medium in which they are found, and that the rest of the radiation corresponds to uranium; an estimate of errors made in obtained measurements would also be made.

ACKNOWLEDGMENTS

The authors of this paper, the technical directors of Project MARNA from the CSN and ENUSA, would like to thank everyone who in one way or another has made it possible to undertake Project MARNA, and in particular the following:

• Junta de Energía Nuclear
All members of the Uranium Prospecting Division of the former Junta de Energía Nuclear, whose hard work has made it possible to have access today to invaluable data.
Javier Cerrajero, Mining Engineer, and Alfredo Crego, Chemist, who were members of the aerial prospecting team of the former Junta de Energía Nuclear, and Francisco de Pedro, Chemist, who introduced aerial prospecting techniques in Spain.

• Consejo de Seguridad Nuclear
Jesús Alegría Alonso, Physicist, and Enrique Velázquez, Physicist.

• Empresa Nacional del Uranio, S.A.
All members of the Uranium Prospecting Division, whose hard work has made it possible to have access today to invaluable data.
In addition, the following people have participated in Project MARNA:
Joaquín Botas, Mining Engineer, José María Josa García, Doctor of Chemistry, Teófilo Concha Sánchez, Mining Engineer, Francisco Marín Blanco, Mining Engineer, Mariano Durán Cabello, Pedro Garrido Ancos, Adolfo Domínguez Vega, Aitor Quintana and Olga Gutiérrez Fernández.

• Universidad de Extremadura
Department of Physics. Professors: Antonio Baeza, C. Miró, M. del Río and J.M. Paniagua.
Computer Science Department. Professors: José Moreno del Pozo, Manual Cabello Requena and Tomás Berjoyo.

• Universidad de Salamanca
Department of Geology. Professors: María Candelas Moro Benito, María Luisa Cembranos, Andrés García Luis and Agustina Fernández Fernández.
In addition: Vicente Alfageme, Jesús Cordero Zarza, Jesús Cruz Jiménez, Roberto Javier García Gil, Margarita Gil Acero, Miguel Angel Herrero González, José María Montero Gómez, Elena Sánchez, Jesús Sánchez Sánchez and María Susana Timón Sánchez.

• Escuela Universitaria Politécnica de Mérida
Topography. Professors: María Eugenia Polo García and Jose Antonio Gutiérrez Gallego.
All of the above have participated in one way or another in Project MARNA.

Enrique SUÁREZ MAHOU is a geologist and pharmacist with 34 years of experience in the nuclear field, and was professor of Uranium Geology in the Universidad Complutense in Madrid. Specializing in uranium prospecting in the Junta de Energía Nuclear, he worked as an expert on several projects for the International Atomic Energy Agency (IAEA). He then joined the Consejo de Seguridad Nuclear (CSN), where he has worked on issues concerning siting of nuclear power plants (NPP) and waste storage facilities, and he has participated as an IAEA expert in drawing up international standards for NPP and waste storage siting. At present, he continues his work in the CSN on siting issues and on technical direction of Project MARNA.

José Angel FERNÁNDEZ AMIGOT is a mining engineer with 34 years of experience. He was professor of economic geology in the University of Salamanca and a specialist in uranium prospecting and deposit evaluation in the Junta de Energía Nuclear. He then joined the Empresa Nacional de Uranio (ENUSA), where he occupied the posts of Deputy Director of the National Uranium Prospecting Plan, Prospecting Director and Deputy Director of ENUSA's prospecting and mining division. He participated in the evaluation of prospecting and/or mining projects in 24 countries. He is an IAEA uranium prospecting expert. At present, he is technical director of Project MARNA.