Earth Syst. Sci. Data Discuss.,
https://doi.org/10.5194/essd-2018-160-RC1, 2019

Open Access Earth System Science Data Discussions

Interactive comment on "30 years of European Commission Radioactivity Environmental Monitoring Database (REMdb) – an open door to boost environmental radioactivity research" *by* Marco Sangiorgi et al.

Anonymous Referee #1

Received and published: 13 February 2019

Referee comments:

30 years of European Commission Radioactivity Environmental Monitoring Database (REMdb) –an open door to boost environmental radioactivity research by Marco Sangiorgi et al.

The manuscript deals with a database containing radioactivity data from environment, food chains etc. The database data flow relies on the EU member states' authorities that regularly send national data to the European Union. The paper is well written

Printer-friendly version

Discussion paper

and it deserves to be published, especially as the existence of REMdb is not that well known. Even I, after 30 years work experience with environmental radioactivity, had never heard of such a resource. I suggest publication of the manuscript in Earth System Science Data once the authors have taken into consideration some minor suggestions found below.

General comments

To put the REMdb to a wider context I wonder if similar more or less public databases are available elsewhere? Are the MS competent authorities the only data providers? University datasets often provide useful information and nowadays the funding organizations often require an open data policy. Are there plans to extend the time period backwards from 1984? Important data was gathered during the period of atmospheric weapons testing.

Detailed comments

Citation on page 2, line 23: Do the authors mean this? International Atomic Energy Agency & World Health Organization. (âĂŐ1996)âĂŐ. International basic safety standards for protection against ionizing radiation and for the safety of radiation sources. Vienna : International Atomic Energy Agency. http://www.who.int/iris/handle/10665/41593

Page 5, line 24: "In 1996, during the Chernobyl accident, there was. . ." 1986?

Page 6, line 31: "In fact, gross beta analysis does not detect weak beta-emitters such as those emitted by 3H, 14C, 35S and 129I." Maybe the authors should tell that total beta activity results are always dependent on the instrument used. Some instruments can measure even low-energy beta particles.

Page 7, lines 8-12: Maybe the gaseous iodine should also be discussed.

Page 7, Lines 13-14: "In most countries filters are changed daily and analysed for total beta activity following the decay of radon decay products." How about "after the decay

of short-lived radon progeny

Page 7, lines 17-19: " 137Cs and 7Be are normally measured with a gamma spectrography at the same time, therefore the amount of reported measurements for both nuclide should be the same, but it does not happen because of lack of harmonization between countries." spectrography -> spectrometry? both nuclide -> both nuclides? Maybe the amount of reported measurements for both nuclides differ also due to "<MDA" values?

Page 7, lines 21-22. Is beryllium-7 significant from dose point of view? If so, please, add a literature reference.

Page 7, lines 25-31: Please, clarify the term "surface water". Does it mean fresh water in lakes and rivers or is also surface water of oceans included? I would expect the radionuclide content of water and intake by drinking to be negligible compared to aquatic food chains ending to man.

Page 8, lines 9-11. Is the high Cs-137 content of ocean water in the Irish Sea due to Sellafield emissions or the Chernobyl accident?

Page 8, lines 20-21: "Eventual presence of 3H, 90Sr and 137Cs and radium may also be due to man's activities." Isn't the presence of Sr-90 and Cs-137 solely due to anthropogenic activities?

Interactive comment on Earth Syst. Sci. Data Discuss., https://doi.org/10.5194/essd-2018-160, 2019.

Earth Syst. Sci. Data Discuss.,
https://doi.org/10.5194/essd-2018-160-RC2, 2019

Open Access Earth System Science Data Discussions

Interactive comment on "30 years of European Commission Radioactivity Environmental Monitoring Database (REMdb) – an open door to boost environmental radioactivity research" *by* Marco Sangiorgi et al.

Anonymous Referee #2

Received and published: 16 February 2019

General comments

The manuscript "30 years of European Commission Radioactivity Environmental Monitoring Database (REMdb) – an open door to boost environmental radioactivity research" describes the REMdb database which is a product of a more than a three decade-long radioactivity monitoring effort and collaboration of European member states. The long time span, vast geographical coverage, variety of sample types and the immense number of measurement records result in an invaluable dataset, which will undoubtedly prove of great value for the scientific community. In this light, the

Printer-friendly version

Discussion paper

manuscript fits very well into the scope of the journal “Earth System Science Data” and can be considered for publication after the authors address the comments posted below.

The manuscript provides links to yearly and bulk datasets which can be downloaded as Excel files. Data from REMdb can also be accessed by an online query tool where the user can personalise the search by location, sample type, observation period, export format etc. The files on the provided links and the files provided by the online query tool are compliant with the descriptions provided in the Data Availability section.

The manuscript accompanying data does, however, have a major issue which the authors should discuss with the Editor before revision. The present database is composed of two datasets. While the first one spanning between 1984-2006 (De Cort et al., 2007) is compliant with the data policies posted on ESSD websites and further elaborated in a recent Editorial (Carlson and Oda, 2018), the second dataset (2007-2016) is not. Namely, it does not have a DOI nor is it fully publicly available (explicit request by email is needed for access; P10 L18). Additionally, the part of the Disclaimer in P11 L10-11 (“The European Union reserves the right to . . . discontinue temporarily or permanently, the REM Database. . .”) could prove controversial regarding the above mentioned data policies of ESSD.

Specific comments

In P1 L9 the DG abbreviation is not explained.

P3 L10 and P1 L17: The abstract says the database contains measurements since 1984, while in page 3 it says since 1988.

P7 L15 and Fig. 8: “Figure 8 shows the amount of measurements by country for 137Cs and 715 Be in the air.” For unambiguity the authors should clarify that this refers to the total amount of measurements in the database.

P7 L26: “aquatic” is probably more appropriate than “marine”?

Section 4: The “Data availability” section should include procedure for data after 2006, i.e. it should be explicitly stated in P10 L18 that the full database also contains measurements after 2006. Additionally, I suggest the authors do not only mention, but also include a short description of the REMdb online query tool and its functionality as it offers useful search options and additional export formats which many readers could find beneficial.

P10 L11-14: The abbreviations used in the Excel files should be mentioned in the paper, for example: “locality name (LOC_NAME),. . ., apparatus description (APT_DESCRIPTION), nuclide (NUC_CODE). . .”

Figure design of the graphs in the manuscript is variable, for example: some have a frame (Figs. 2, 8-11) and some do not (Figs. 3-6); font sizes of axis titles in Figs. 5 and 6 are much larger compared to similar graphs in the manuscript.

Fig. 7 shows the sampling distribution from 13 years ago. As the authors present the database up until 2016, a more recent picture would be appropriate.

Fig. 8: The legend in the figure is so small that the reader cannot see which symbols are used for 137Cs, total beta and 7Be

Fig. 9a: Again the legend is too small to recognise the symbols of the radionuclides

Figs. 9a and 9b: There should be only one subscript per figure

Figs. 8-11: I suggest to add “in REMdb” to avoid ambiguity (e.g. “Total amount of measurements in REMdb (dense network) for sample type airborne particulates. . .”)

Technical corrections

P2 L4: “. . .the rest being associated. . .” instead of “. . .being the rest associated. . .”

P3 L24: under or equipped, not both

P4 L15: “. . .since year 2002, but Poland made available samples for year 1986” should

probably be "...in 2002, but Poland made available measurements since 1986"?

P4 L31: "each other" instead of "each other's"

P5 L7: "It is" instead of "'tis"; "...attention to field..." instead of "...attention over field..."

P5 L8: "represents the best" instead of "represents best"

P5 L12: "in De Cort et al. (2004)" instead of "in (De Cort, et al., 2004)"

P5 L17: "...106 measurements..." is probably "...10^6 measurements..."?

P5 L25: "1996" is probably "1986"?

P5 L26-27: "gradually lost" instead of "lost gradually"

P8 L9: "Povinec et al. (2003) analyse..." instead of "(Povinec et al., 2003) analyse..."

P8 L27: "(http://www.radioecology-exchange.org/content/monitoring-sr-90-and-cs-137-milk-finland)." instead of "(http://www.radioecology-exchange.org/content/monitoring-sr-90-and-cs-137-milk-finland respectively)"

P9 L15: Link does not work (browser message is: server IP address could not be found).

DOIs are missing in the References (P11 L18, P11 L23,...). The readers would also benefit if the authors provided URL's and/or DOI's of public reports in the References (e.g. De Cort et al., 2004)

References

Carlson, D. and Oda, T.: Editorial: Data publication – ESSD goals, practices and recommendations, Earth Syst. Sci. Data, 10, 2275-2278, https://doi.org/10.5194/essd-10-2275-2018, 2018. De Cort, M., Tollefsen, T., Marsano, A. & Gitzinger, C.: Environmental Radioactivity in the European Community 2004- 2006, http://dx.doi.org/10.2788/25616. 2004. De Cort, M.; Sangiorgi, M.; Hernandez Ce-

ballos, M.A.; Vanzo, S.; Nweke, E.; Tognoli, P.V.; Tollefsen, T.: REM data bank - Years 1984-2006. European Commission, Joint Research Centre (JRC) [Dataset] doi:10.2905/jrc-10117-10024 PID: http://data.europa.eu/89h/jrc-10117-10024 . 2007

Interactive comment on Earth Syst. Sci. Data Discuss., https://doi.org/10.5194/essd-2018-160, 2019.

Printer-friendly version

Discussion paper

Earth Syst. Sci. Data Discuss.,
https://doi.org/10.5194/essd-2018-160-RC3, 2019

Open Access Earth System Science Data Discussions

Interactive comment on "30 years of European Commission Radioactivity Environmental Monitoring Database (REMdb) – an open door to boost environmental radioactivity research" *by* Marco Sangiorgi et al.

Anonymous Referee #3

Received and published: 19 February 2019

This natural background is enhanced by nuclear accidents . . .. . .

It's better to explain, among others, that efficient dose for the population and workers is calculated considering the natural radioactivity background and excluding the artificial one. So in general it's better distinguish between natural background and increments from the same natural background.

On page 4 Maybe it should be spent few word on the type of scientific checks: considering that generally there are formats to be filled sent in various countries -it's difficult

Printer-friendly version

Discussion paper

to understand which kind of control it was done: which is the quality of the control.

OnPag.7 Airborne generally it's made a measurement after an hour and a half and it's waited the decay of the short-lived products of Radon, lead and bismuth.

Finally, for the figures, A part from the captions in line with the base of rectangle that contains them, I would suggest that - more than the progressive order generated by the date of membership of each country – starting from figure 3, it would be better an ascending or descending order, this order could be determined by the number of measurements carried out by each country; even if a country has started after years, this country could be able to take a number of measurements greater than those countries who have taken part from the beginning. (As in Figure 4, and Figure 2 at Pag18). However I point out that there are two figures

Interactive comment on Earth Syst. Sci. Data Discuss., https://doi.org/10.5194/essd-2018-160, 2019.

Earth Syst. Sci. Data Discuss.,
https://doi.org/10.5194/essd-2018-160-RC4, 2019

Open Access Earth System Science Data Discussions

Interactive comment on "30 years of European Commission Radioactivity Environmental Monitoring Database (REMdb) – an open door to boost environmental radioactivity research" *by* Marco Sangiorgi et al.

Anonymous Referee #4

Received and published: 27 February 2019

General Comments: Long-term (30 years) environmental radiation monitoring datasets at the large regional scale (Europe) are described in detail. The data are interesting and valuable for the general public and scientific community. This paper is well written and suitable to be published in Earth System Science Data. In the following lines, authors will find minor comments: Page 5 Line 7: "Itis" should be "It is". Line 18: "106 measurements" should be "106 measurements". Line 19: "Surface water and Drinking water" seems not reasonable category. Page 15 Figure 2: "E+0" is 1? If so, Figure 2, 8, 9, 10, 11 should be same with Figure 3 & 5. Page 16 Table 1: "Altitude" is more

Printer-friendly version

Discussion paper

suitable than “Height”. Page 17 Figure 4: What’s the meaning of “logarithmic scale”? Is 1×107 a logarithmic value? In general, plants include trees, grass, moss, etc. In the sample category of “Trees, Plants, Moss, Grass”, “Plants” specifically refer to what?

Interactive comment on Earth Syst. Sci. Data Discuss., https://doi.org/10.5194/essd-2018-160, 2019.

Earth Syst. Sci. Data Discuss.,
https://doi.org/10.5194/essd-2018-160-RC5, 2019

Open Access Earth System Science Data Discussions

Interactive comment on "30 years of European Commission Radioactivity Environmental Monitoring Database (REMdb) – an open door to boost environmental radioactivity research" *by* Marco Sangiorgi et al.

Anonymous Referee #5

Received and published: 28 February 2019

General comment:

'30 years of European Commission Radioactivity Environmental Monitoring Database (REMdb) – an open door to boost environmental radioactivity research' document contain useful information for people interested to environmental radioactivity research and can be considered for publication.

Comments:

P2 L10-11 Please, consider if to remove/rephrase the last sentence (Nevertheless...).

Printer-friendly version

Discussion paper

P3 L13 'seem reasonably stable' do you mean that this is a complete data sample from each MS?

P3 L28 Please, describe in the text the flow shown in figure 1

P4 L18-19 Even considering... The wide variability of the number of measurements per country could be due to a different number of measurement sites, a different area of the countries, specific country properties, etc. is it correct? If yes, I suggest changing the sentence taking it into account.

P4 L25 it could be useful to specify the main checks.

P5 L 12-33 it might be useful, to understand the power of the database, to mention the total number of variables currently available.

P7 L7 Please, consider if to change the subsection title with Air measurements.

P7 L25 Please, consider if to change the subsection title with Water measurements.

P8 L22 Please, consider if to change the subsection title with Milk measurements.

P9 L1 Idem.

P9 Section 4 Is it necessary to list all the files? I suggest to change the list with a sentence.

Minor comments:

P1 L28 and P2 L18 ionising-> ionizing.

P3 L31 A dot is needed at the end.

P4 L22 organisation-> organization.

P5 L17 sample type -> sample category.

References:

references are not homogeneously reported

Figures:

General comment, please, make the fonts size homogeneous.

Fig. 2 I suggest to remove the sentence in parenthesis (sentence already mentioned in the text) and add a dot to the end of the caption.

Fig.3 I suggest to remove the sentence in parenthesis and add the dot.

Table 1 Is it 'less than' mandatory? (see the text P5 L8).

Fig. 7 Add a dot at the end of the caption.

Table 2 Please, move Radionuclide category at the center of the field and add a do

Fig 8-11 The figures are not clearly legible.

Figs 9-11 please, change 'as recommended in Table 2' with 'recommended in (Basic Safety Standards, 2014)'.

Interactive comment on Earth Syst. Sci. Data Discuss., https://doi.org/10.5194/essd-2018-160, 2019.

Printer-friendly version

Discussion paper

Earth Syst. Sci. Data Discuss.,
https://doi.org/10.5194/essd-2018-160-RC6, 2019

Open Access Earth System Science Data Discussions

Interactive comment on "30 years of European Commission Radioactivity Environmental Monitoring Database (REMdb) – an open door to boost environmental radioactivity research" *by* Marco Sangiorgi et al.

ARUNKUMAR ANBU ARAVAZHI (Referee)

anbu.arunkumar@gmail.com

Received and published: 11 March 2019

11th March 2019 Dear Authors, Thanks for the manuscript (MS) essd-2018-160 on "30 years of European Commission Radioactivity Environmental Monitoring Database (REMdb) – an open door to boost environmental radioactivity research". I always found this work very relevant and ground-breaking in a way. The paper is well written and it deserves to be published, especially as the existence of REMdb is not that well known to all. Even after 30 years work experience with environmental radioactivity, had never heard of such a resource. I suggest publication of the manuscript in Earth System

Printer-friendly version

Discussion paper

Science Data. However, the text still suffers from spacing problems, namely, the space between the values and its units. Please provide those updates and be very thorough! Below I provide an incomplete list of consistent problems in many phrases. Once authors have completed those very relevant details to satisfaction we can move ahead with a final check for publication. I hope we could reach that level for such an important topic indeed. Page 3, L17: The abstract says the database contains measurements since 1984, while in page 3 it says since 1988, REMdb was set-up in 1988 explain. Page 5, line 24: "In 1996, during the Chernobyl accident, there was. . .. . .:" Chernobyl accident took place at 1986? Kindly clear it. Page 9 L15: Link does not work (browser message is: server IP address could not be found). Kindly verify.

Fig. 7 shows the sampling distribution from 13 years ago. As the authors present the database up until 2016, a more recent picture would be appropriate.

References kindly follow the journal format

Thanks once more to the authors and more then with their replies and update

---

Interactive comment on Earth Syst. Sci. Data Discuss., https://doi.org/10.5194/essd-2018-160, 2019.

30 years of European Commission Radioactivity Environmental Monitoring Database (REMdb) – an open door to boost environmental radioactivity research

Marco Sangiorgi[1], Miguel A. Hernández Ceballos[1], Giorgia Iurlaro[2], Giorgia Cinelli[1], Marc de Cort[1]

[1]European Commission, Joint Research Centre (JRC), Ispra, Italy.
[2]ENEA, Ispra, 21027, Italy

Correspondence to: Marco Sangiorgi (marco.SANGIORGI@ec.europa.eu)

Abstract. The Radioactivity Environmental Monitoring data bank (REMdb) was created in the aftermath of the Chernobyl accident (1986) by the European Commission (EC) – Directorate-General Joint Research Centre (DG JRC), sited in Ispra (Italy). Since then it has been maintained there with the aim to keep a historical record of the Chernobyl accident and to store the radioactivity monitoring data gathered through the national environmental monitoring programs of the Member States (MSs). The legal basis is the Euratom Treaty, Chapter III Health and Safety, Articles 35 and 36, which clarifies that MSs shall periodically communicate to the EC information on environmental radioactivity levels. By collecting and validating this information in the REMdb, JRC supports the DG for Energy in its responsibilities in returning qualified information to the MSs (competent authorities and general public) on the levels of radioactive contamination of the various compartments of the environment (air, water, soil) on the European Union scale. The REMdb accepts data on radionuclide concentrations from EU MSs in both environmental samples and foodstuffs from 1984 onwards. To date, the total number of data records stored in REMdb exceeds five million, in this way providing the scientific community with a valuable archive of environmental radioactivity topics in Europe. Records stored in the REMDdb are publicly accessible until 2011 through an unrestricted repository "REM data bank - Years 1984-2006" http://doi.org/10.2905/jrc-10117-10024 (De Cort et al., 2007), and "REM data bank - Years 2007-2011" doi:10.2905/de42f259-fafe-4329-9798-9d8fabb98de5 (De Cort et al., 2012). Access to data from 2012 onwards is granted only after explicit request, until the corresponding monitoring report is published. Each data record contains information describing the sampling circumstances (sampling type, begin-end time), measurement conditions (value, nuclide, apparatus, etc.), location and date of sampling and original data reference. In this paper the scope, features and extension of the REMdb are described in detail.

1 Introduction

Radiation occurs when energy is emitted by a source and then travels through a medium, until it is absorbed by matter. In this sense, radiation is a fact of life as every person, animal and object is subjected to radiation every day. Radiation can be either ionizing or non-ionizing. Whenever we refer to radiation in this paper, we mean ionising radiation unless we say

otherwise. By definition (ICRP, 1990), ionizing radiation is a radiation with enough energy to break chemical bonds; this includes X rays and gamma rays, while a source is anything which may cause exposure, such as by emitting ionizing radiation or by releasing radioactive substances or radioactive material, and can be treated as a single entity for purposes of protection and safety.

About 80% of radioactivity in the environment derives from natural sources (background radiation), the rest being associated with the creation and use of artificial sources by human activities, such as medical applications. The main natural sources are: cosmic radiation which is generated by interaction of primary radiation (mainly protons) with atoms of the atmosphere (e.g. Cinelli et al., 2017); terrestrial radiation which is produced as a consequence of the presence of radioactive materials in the Earth's crust, such as ^{40}K, ^{238}U and ^{232}Th and their daughter nuclides (UNSCEAR, 2008), and internal radiation, which is generated by the presence of ^{40}K, ^{14}C and ^{210}Pb in human bodies from birth. As a consequence of anthropogenic activities, such as Chernobyl and Fukushima (e.g. Imanaka et al., 2015), detonations of nuclear weapons (e.g. Gabrieli et al., 2011), nuclear waste handling and disposal, medical procedures (e.g. diagnostic X-rays, radiation therapy) (e.g. Alkhorayef et al., 2018) and mining (e.g. Carvalho et al., 2014), the background radioactivity level is increased.

The hazards to people and the environment from radioactive contamination depend on the nature of the radioactive contaminant, the level of contamination, and the extent of the spread of contamination (e.g. Ogundare and Adekoya 2015). Elevated levels of radioactive elements in the environment, resulting from natural or anthropogenic activities, can be a significant problem for the ecosystem and may threaten human health, especially if they build up in the food chain. Consequently, ionising radiation has to be assessed and, if necessary, controlled. In this line, the importance of an adequate characterization of the variability and uncertainty in exposure assessments for human health risk assessments has been emphasized by several national and international organizations (e.g. WHO/FAO, 2006; InVS and AFSSET, 2007). Monitoring radioactivity in the environment is of utmost importance in order to observe trends over time and to verify that there is compliance with the Basic Safety Standards (2000/473/Euratom), (2013/59/Euratom), (IAEA, 2014).

The transboundary nature and the amount of the contamination during the Chernobyl accident triggered the international organisations to promote international cooperation and communication in nuclear, radiation and emergency preparedness and response. Under the EURATOM treaty (Council Decision 87/600/EURATOM of 14 December 1987), article 36 requires the competent authorities of each Member State (MS) to provide regularly the environmental radioactivity monitoring data resulting from their Article 35 obligations to the European Commission (EC) in order to keep EC informed on the levels of radioactivity in the environment (air, water, milk and mixed diet) which could affect population.

The continuous communication of environmental radioactivity monitoring data after the Chernobyl accident to the EC from MSs triggered the need to integrate, store and organize them so that the collection of information can be easily accessed, managed and updated. With this purpose, the amount and diversity of environmental radioactivity data received from the MSs have been and are routinely stored in the Radioactivity Environmental Monitoring data bank (REMdb) (https://rem.jrc.ec.europa.eu/RemWeb/), which is managed by the EC Joint Research Centre (JRC) sited in Ispra (Italy) as part of its Directorate General for Energy (DG ENER) support programme. REMdb is the base to annually inform of the

radioactivity levels in the environment in the European Community, as stated in art. 35 - 36 of the Euratom Treaty. Every MS has its own database and they submit just a part of their measurements to REMdb.

Environmental radioactivity databases contribute to scientific knowledge of the processes affecting radionuclides distribution and the sources introducing radioactivity into the environment. They provide critical inputs to the evaluation of the environmental radionuclide levels at regional and global scale, deliver information on temporal trends of radionuclides levels and identifies gaps in available information, as well as they are used as a basis for the assessment of the radiation doses to local, regional and global human populations and biota. In this sense, REMdb makes accessible and understandable to a wider audience radioactivity measurements made by all MS in air, water, milk and mixed diet in the aftermath of the Chernobyl accident, and brings to the scientific community research opportunities to exploit a unique collection of near 5 millions of environmental radioactivity measurements since 1984.

This paper addresses the scope, features and extensions of REMdb with the intention to provide the scientific community with easy access to these data. Since REMdb is constantly growing, this paper decided to refer to data up to 2016 which are almost fully validated at the time this paper is written. The REMdb measurements are public until 2011 (http://data.jrc.ec.europa.eu/collection/id-0117), while access to data from 2012 is restricted until relative monitoring reports are released and may be granted only after explicit request. In this paper, REMdb data and monitoring networks are described in Sect. 2, as well as the applied quality control methodology. Then, Sect. 3 presents the status of REMdb for the sampling media recommended by EC. Finally, data record details and conclusions are reported in Sect. 4 and 5 respectively.

2 Data and methods

The primary scope of the REMdb is to provide a unique and single framework for working with environmental radioactivity data originating from many and diverse sources. REMdb was set-up in 1988 and collects in a harmonized format environmental radioactivity data for environmental samples, foodstuffs and other media from 1984 onwards.

There has been significant effort in updating the REMdb at a frequent, regular basis in a consistent and systematic way to preserve the integrity of information embodied to the database. The database is currently hosted on an internal JRC server under, equipped with the latest version of Oracle 12c RDBMS (Relational Database Management System). The servers are within the JRC internal firewall. They are centrally managed and adhere to all JRC security guidelines and policies. They are accessible under custom applications (DST, RemWeb, etc.) and third-party software (SQL Developer) through standard communication protocols like SSH, SFTP, and TCP/IP. Automatic backups occur on the server.

Figure 1 sketches the process from the collection of samples to the final store of data in REMdb. First sample are collected and radioactivity levels are measured by the MSs in specialised and accredited laboratories; once measurements are processed they are made available to the National Contact Points and submitted into REMdb by using a tool called REM Data Submission Tool; submitted data are checked by JRC, shown back to those who have submitted them and validated. Finally, after validation, data are processed for the creation of a yearly monitoring report and made freely available to the

public. An important tool in this process is the "REM data submission tool" (REM DST) by which data are sent on a regular basis by the national contact points of EU28 to the JRC. It is worth pointing out that JRC assists MSs in using REM DST correctly by organising regular training courses (e.g. the 2018 edition was held on 13-14 November).

Once gathered the data from MSs, the database is conceived as a series of data records, each one containing a single measurement of a single radionuclide on a single sample, and does not include summary statistics, which have to be created ex post.

Nowadays, the total number of data records stored in REMdb exceeds five million. Figure 2 shows the amount of data stored in REMdb from 1984 to 2016. It is clear that Chernobyl accident generated a peak in the amount of measurements and created consciousness about the importance of monitoring radioactivity. Additionally, the increase of data observed from 1994 to 1996 is also associated with Chernobyl, due to the compilation of contamination data from countries or regions in Europe resulting from the radioactive material released during the accident. For instance, after data validation and inter-comparison, the "Atlas of caesium deposition on Europe after the Chernobyl accident" was published in 1998 De Cort et al. (1998).

The yearly evolution of measurements stored in REMdb is also influenced, as one can expect, by the amount of countries which joined the REMdb since its creation. The amount of submitted measurements ranges from one million for Germany and France to ten thousand for Ireland, Denmark and Greece. Figure 3 shows the year in which each country started submitting measurements to REMdb, and displays the great difference in the amount of measurements from country to country (in logarithmic scale). Czech Republic, Lithuania, Estonia, Latvia, Poland and Bulgaria (marked in red) joined REMdb in 2002, but Poland made available samples since 1986. Slovenia (marked in orange) joined in 2003; Slovakia, and Romania (marked in yellow) joined in 2004; Cyprus (marked in light green) in 2006 and Malta (marked in dark green) in 2008. REMdb contains a large and representative number of measurements for each MS, in spite of a large range of variability in the amount measurements from country to country.

2.1 Quality control

Submitted data quality control is a duty of the laboratories which have to use defined procedure for tests and calibration including sampling technique. The laboratories have to participate to periodical inter-comparison tests for the specific matrix and measurements methods. Data providers and MSs' competent authorities are responsible of their submitted data.

The value of a database system is dependent on the quality of primary data, the organisation and reliability of the data entry and verification systems, and the accessibility of data. It has to be noted that continuous maintenance and frequent updates of the database are also important issues confronted on the practical end.

As part of JRC control procedures, all data entered into the database are internally reviewed, shown back to the MSs as they would appear in REMdb and checked once more. When the corresponding data provider approves them, they are stored and flagged as "verified". By doing this, spurious or incomplete datasets are avoided before making them available to all users.

Further controlled and documented releases of summarised data are timetabled such that values are not changing on a regular basis.

2.2 Measurements and Monitoring networks

Measurements carried out by the MSs can be very different from each other, as they can be referred to different sample types (water, air, food, soil, etc.), different nuclides, different apparatus used for the measurement, different sampling period, etc. REMdb streamlines the various formats adopted in the EU for reporting routine environmental measurements. In order to bring some harmony and classify the information, some standard sample categories or types are defined and some minimum requirements of the information collected in REMdb are set. Table 1 indicates the information requested in order to be stored as a record in REMdb; not all fields are mandatory. There are three main blocks of information (Locations, samples and measurements), which mainly refer with source of data and information necessary to describe the procedures for sample collection, treatment, analysis and measurement as performed by the original laboratories (Nweke, et al., 2015).

It is worth pointing out the attention to field "Less Than" of the measurements record: this field is not mandatory and represents the best that can be done with the instruments which vary from country to country. The value is used to indicate that the results of measurements are reported "less than a given value" or "below a threshold detection limit" (called Lower Limit of Detection). This field is often left empty and no measurements are provided even if they were carried out because considered too low to worth being reported.

A detailed classification of sample types or sample categories in REMdb can be found in De Cort, et al. (2004). There are eight main categories in this classification: 1) Environmental samples, 2) uncultivated products, 3) crops, vegetable and fruit, 4) manufactured agricultural products, 5) animal products, 6) dairy products, 7) Technical samples and 8) mixed diet. Within this classification, it is necessary to highlight that sample types can also have subtypes, for example, water samples is subdivided in surface water samples and drinking water samples. Figure 4 shows the amount of single measurements per sample type stored in REMdb. This figure shows how most of sample types have more than a hundred records. One can observe that the most populated category is air-airborne particulate with more than 10^6 measurements, while a considerable amount of records is also available for the freshwater ecosystem (Surface water and Drinking water). On the contrary, some sample types and/or subtypes were foreseen but not populated at all, such as Amniotic fluid which belongs to human biological samples.

Nowadays around 70 radionuclides are regularly reported and stored in REMdb. Figure 5 shows the amount of measurements of the most sampled ones stored in the database; amount which varies greatly from year to year, from country to country and also from nuclide to nuclide. In 1986, during the Chernobyl accident, there was a big and sudden increase in the number of different radionuclides reported and stored in REMdb (almost 100), while in 1994 there was a peak of 110; afterwards it stabilized around 70. In a similar way, some nuclides where of more concern soon after the accident and gradually lost importance due to their short life (e.g. ^{131}I and ^{134}Cs), while others gained more and more importance because

of their applications in other fields, such as the ^{7}Be which is used as an atmospheric tracer (e.g. Lozano et al., 2012). Germany, France and Italy are the countries which report more radionuclides (about 100); UK and Hungary take into consideration about 60, while the remaining nations focus their attention on 20 radionuclides or even less, which is anyway much higher compared to what recommended by the Commission Recommendation 2000/473/Euratom: gross alfa/beta, ^{137}Cs, ^{3}H, ^{90}Sr, ^{40}K, ^{14}C, ^{7}Be.

Figure 6 shows how the main radionuclides stored in REMdb are also those with the largest country coverage. For example, more than 30 countries measure total-beta, ^{137}Cs and ^{7}Be. Looking at this figure, 72% of the total number of radionuclides is measured in more than 20 countries, and 22% in more than 30 of them. This fact is associated with the number of monitoring stations deployed in each country reporting high-quality measurements to REMdb. In Europe, different approaches in the definition of the national environmental monitoring networks have been adopted, based on socio-economic considerations about where to install monitoring stations.

2.3 Dense and sparse network

Figure 7 shows an example of the sampling locations distributed all over Member States' territories in 2006 corresponding to ^{137}Cs in airborne particulates. Differences in the number of sampling locations between both plots are associated with the definition of dense and sparse monitoring networks (2000/473/Euratom). The sparse network is included in the dense network, being a subset of it. There is no distinction between the structures of data stored in REMdb as dense or sparse network: both kinds of data comply with the same requirements. While dense network refers to a monitoring network that comprises sampling locations distributed throughout the Member State's territory and used by the Commission to compute regional averages for radioactivity levels in the Community, sparse network groups those locations in which high-sensitivity measurements are performed. A sparse monitoring network, means therefore a monitoring network which comprises for every geographical division and for every sampling medium at least one representative location of that geographical division.

3. Status of REMdb as recommended by EC

Activities such as the medical uses of radiation, the operation of nuclear installations, the production, transport and use of radioactive material, and the management of radioactive waste must be subject to standards of safety (2013/59/Euratom). The Commission recommendation of 8 June 2000 on the application of Article 36 of the Euratom Treaty (2000/473/Euratom) concerning the monitoring of the levels of radioactivity in the environment for assessing the exposure of the population as wholes suggests that some sample types and radionuclides are of more concern due to their higher contribution to the annual dose. Table 2 shows the sample types and radionuclide categories to be monitored and reported to the Commission. These radionuclides are therefore measured and reported thoroughly by the MSs, as can be seen in Figure 5.

All the measured radionuclides except ^{90}Sr and ^{137}Cs can be of either natural or artificial origin. The two exceptions are of artificial origin, mainly from past atmospheric weapons testing and from radioactive routine or accidental discharges from nuclear facilities.

Gross alpha and gross beta measurements are appropriate to characterise the total radioactivity of the sample. Gross beta is, by definition, the total measured beta activity in a sample; beta from tritium and in general very low energy beta emitters are normally not considered and short lived radon daughters are excluded through a sufficient delay time (e.g. five days) before counting. Gross beta activity results are always dependent on the instrument used and even if some instruments can measure low-energy beta particles, gross beta analysis does not detect weak beta-emitters such as those emitted by ^{3}H, ^{14}C, ^{35}S and ^{129}I. Residual beta is the measured gross beta activity minus ^{40}K activity, being the latter the main natural source of activity in water.

Following the contamination of the environment with radionuclides, the population is exposed through both external and internal irradiation pathways. From a radio-ecological point of view, the behaviour of radionuclides in the environment and the interaction (uptake, excretion) with food organisms (plants, fungi, animals) is essential for the prediction of future internal exposure due to intake of contaminated foods (e.g. Merz et al., 2016).

3.1 Air measurements

Airborne particulate is measured due to its greater radiological significance. Airborne radioactive materials may occur in either gaseous or particulate form. In general, the latter is of greater potential radiological significance because it may be deposited and hence remain in the local environment. For instance, regarding emissions from Fukushima, ^{137}Cs was attached in the size range 0.1−2 μm diameter (Kaneyasu,et al., 2012). Consequently, most national routine monitoring networks measure only the particulate component.

Airborne particulate sampling is carried out by pumping air through filters. In most countries filters are changed daily and analysed for total beta activity following the decay of radon decay products. Individual radionuclide analyses are performed weekly, monthly or quarterly. Figure 8 shows the total amount of measurements in the database by country for ^{137}Cs and ^{7}Be in the air. Man-made alpha-emitting aerosols are rarely measured by routine monitoring networks as they are usually undetectable, even close to the nuclear installations where they are produced. ^{137}Cs and ^{7}Be are normally measured with a gamma spectrometry at the same time, therefore the amount of reported measurements for both nuclides should be the same, but it does not happen because of lack of harmonization between countries.

^{137}Cs is of major concern because it is the most abundant anthropogenic radionuclide and, because of its high volatility, the radiation type it emits and its biological activity (chemical analogue of potassium). On the other hand, the cosmogenic radionuclide ^{7}Be is important because it has the highest activity concentration in air (troposphere) among all cosmogenic radionuclides (Eisenbud and Gesell, 1997) and gives its contribution to the annual effective dose, which is about 30 nSv/year (Magnoni, 2018). As a consequence, ^{7}Be is widely used as aerosol tracer in order to study aerosol transport and removal in the troposphere by testing scavenging parametrizations (e.g. Alonso-Hernandez., 2014).

3.2 Water measurements: Surface and drinking

The presence of artificial radionuclides in aquatic environment results from global fallout from atmospheric nuclear weapons tests, fallout from the Chernobyl accident, discharges of radionuclides from nuclear installations, contributions from nuclear testing sites, past dumping of radioactive wastes, nuclear submarine accidents, loss of radioactive sources, applications of radionuclides in medicine and in industry, and the burn-up of satellites using radionuclides as their power source (Livingston and Povinec, 2000). They pose a number of health hazards, especially when these radionuclides are deposited in the human body through drinking, and can eventually become incorporated into sediments and living species.

Due to man's activities, the fraction of ^{3}H and the presence of ^{137}Cs have to be checked in this sampling media. Natural radionuclides in river water include ^{3}H at levels of [0.02 - 0.1] Bq l^{-1}, ^{40}K [0.04 - 2 Bq l^{-1}], radium, radon and their short-lived decay products [< 0.4 - 2 Bq l^{-1}] (De Cort, et al., 2004), while ^{137}Cs is the most abundant anthropogenic radionuclide present in the marine environment (e.g. Aarkrog et al., 1997).

Surface water is one of the compartments into which authorised discharges of radioactive effluents from nuclear installations are made and hence (mostly rivers, but also sea water very close to the facilities), radionuclides in this sampling media can be either found in the water phase or associated with suspended particles and sediments. For instance, the Chernobyl accident in 1986 contributed significantly mainly to ^{134}Cs and ^{137}Cs inventories in seawater of the Baltic and North Seas, resulting in the Baltic Sea being the most highly contaminated by ^{137}Cs (e.g. Nies and Nielsen, 1996). Povinec et al. (2003) analyse the distribution of anthropogenic ^{137}Cs in surface waters of the NE Atlantic Ocean for the year 2000, reporting mean values from 60±50 Bq m^{-3} for the Irish Sea to 2.1±1.2 Bq m^{-3} for the English Channel.

Samples are either taken continuously and bulked for monthly or quarterly analysis, or alternatively, spot samples are taken periodically several times a year and analysed individually or as a composite. Figure 9a shows the total number of ^{137}Cs and total beta measurements regarding surface water media in REMdb.

Drinking water, on the other hand, is monitored because of its vital importance for man, even though a severe radioactive contamination of this medium is unlikely. Samples may be taken from ground or surface water supplies, from water distribution networks, mineral waters etc. Spot samples are taken a few times a year and, analysed individually or samples are taken daily and bulked for monthly or quarterly analysis. The number of measurements included in REMdb for this sampling media is shown in Figure 9b. Same as for surface water, most important natural radionuclides in drinking water are ^{3}H, ^{40}K, radium, radon and their short-lived decay products, but vary greatly. While eventual presence of ^{3}H may or may not be due to man's activities, ^{90}Sr and ^{137}Cs can be only a consequence of anthropogenic activities.

3.3 Milk measurements

For many contamination scenarios, especially for accidentally released radionuclides, consumption of milk and dairy products has been shown to be one of the most important pathways to the internal dose to the public (UNSCEAR, 2008). As

an example of its importance, monitoring of ^{137}Cs and ^{90}Sr in consumption milk is ongoing since 1955 and 1960 in Sweden (http://projects.amap.no/project/monitoring-of-cs-137-and-sr-90-in-consumption-milk/) and Finland (http://www.radioecology-exchange.org/content/monitoring-sr-90-and-cs-137-milk-finland)

Figure 10 shows the total number of measurements of ^{137}Cs, ^{40}K, and ^{90}Sr in cow's milk per European country. Samples are mostly taken at dairies covering large geographical areas in order to obtain representative samples. They are generally taken on a monthly basis; but sometimes only during the pasture season. Generally, the concentrations of the stable elements calcium (Ca) and potassium (K) are determined because of the similarity of their metabolic behaviour with strontium (Sr) and caesium (Cs) respectively.

3.4 Mixed diet measurements

The aim of measuring radioactivity in mixed diet is to get "integral" information on the uptake of radionuclides by man via the food chain. Samples are taken as ingredients or as complete meals, mostly at places where many meals are consumed (i.e. factory restaurants, schools). The trend is to sample complete meals according to food consumption statistics to give a representative figure for the contamination of mixed diet; it's also very common to analyse single foodstuff and combine them according to local diet style. Knowledge of the contamination of the individual ingredients together with the composition of the national diet can also lead to a representative figure.

Rather than expressing the radioactivity content of foodstuffs per unit weight, it is more appropriate to estimate the activity consumed per day per person (Bq d^{-1} p^{-1}). Generally, the concentrations of the stable isotopes of calcium and potassium are determined because of the similarity of their metabolic behaviour with strontium and caesium, respectively. Typical values in mixed diet are 0.7 to 1.5 g d^{-1} $person^{-1}$ for calcium and 3 to 4 g d^{-1} $person^{-1}$ for potassium. Figure 11 shows the total amount of measurements for sample type mixed diet, ^{137}Cs, ^{90}Sr and ^{14}C by country, as recommended in Table 2.

4 Data Availability

Environmental radiation monitoring datasets are freely available at JRC Data Catalogue http://data.jrc.cec.eu.int/collection/id-0117 .

Before a datasets may be published, the corresponding monitoring report must be issued first. At the time this paper is prepared, monitoring reports up to year 2011 were published; therefore it's possible to release datasets up to 2011. People are invited to check our data catalogue for updates.

Datasets can be downloaded singularly as Excel files and zipped due to their dimension year by year from 1984 to 2006 by following subsequent PIDs or as a bulk:

"REM data bank - Years 1984-2006 at http://doi.org/10.2905/jrc-10117-10024 (De Cort et al., 2007)

"REM data bank - Years 2007-2011 at http://doi.org/10.2905/de42f259-fafe-4329-9798-9d8fabb98de5 (De Cort et al., 2012)

The fields made available for download are (in brackets is the field abbreviation): locality name (LOC_NAME), country name (COUNTRY_NAME), locality latitude (LOC_LATITUDE), locality longitude (LOC_LONGITUDE), sample type description (STY_DESCRIPTION), sample treatment description (STR_DESCRIPTION), sample begin date time (SAM_BEGINDATETIME), sample end date time (SAM_ENDDATETIME), laboratory name (LAB_NAME), apparatus description (APT_DESCRIPTION), nuclide (NUC_CODE), measured standard activity value MEA_STANDARDACTIVITYVALUE), measured standard unit (MEU_STANDARDUNIT), value type description (VAT_DESCRIPTION). Datasets size can be up to 35 MB and contain up to two hundred lines, each line representing a single record or measurement.

Users can also access the REMdb on-line and retrieve them through personal queries. Monitoring reports from year 1996 to 2011 are also available for download at the corresponding dataset.

For full database access or questions, please write an e-mail to JRC-REMDBSUPPORT@ec.europa.eu

5 Conclusions

This paper provides a synthesis of the online Radioactivity Environmental Monitoring data bank (REMdb). The database presented here contains more than five million of records from 1984 onward concerning radioactivity levels in Europe of air, deposition, water, milk, meat, crops and vegetables; REMdb brings to the scientific community endless of research opportunities. The database is accessible via a web browser and is open to the scientific community. During its more than 30 years of operational life, REMdb grew more and more in amounts of measurements thanks also to more countries joining the project. Nevertheless, experience has shown that its structure could be optimized in order to accommodate users' needs and compare measurements carried out by different laboratories. Future work focuses on maintaining the updates frequency constant, enhance the user's accessibility to original data, and develop a user-friendly interface.

Author contributions

MDC was in charge of REBdb creation and is the main reference for information being the person responsible of the project; MS is the main author, MAHC was the main reviewer and gave technical guidance, GC and GI gave very valuable contribution with their comments.

Competing interests

The authors declare that they have no conflict of interest.

Disclaimer

By accessing the REM Database and its content, the user agrees that the law of the European Union, without regard to principles of conflict of laws, will govern these terms and conditions and any dispute of any sort that might arise between the user and the European Commission. The European Union reserves the right to modify or discontinue temporarily or permanently, the REM Database (or any part thereof) without prior notice to users.

Acknowledgement

The authors would like to thank all the EU Member States for having sent the data and David Carlson for his very helpful and kind support.

References

87/600/Euratom: Council Decision of 14 December 1987, on Community Arrangements for the Early Notification of Information in the Event of a Radiological Emergency." *Official Journal of the European Communities, OJ L* 371 (1987). ELI: http://data.europa.eu/eli/dec/1987/600/oj

2000/473/Euratom: Commission Recommendation of 8 June 2000 on the application of Article 36 of the Euratom Treaty concerning the monitoring of the levels of radioactivity in the environment for the purpose of assessing the exposure of the population as a whole (notified under document number C(2000) 1299) ELI: http://data.europa.eu/eli/reco/2000/473/oj

2013/59/Euratom: Council Directive of 5 December 2013 laying down Basic Safety Standards for protection against the dangers arising from exposure to ionising radiation, and repealing Directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom and 2003/122/Euratom. ELI: http://data.europa.eu/eli/dir/2013/59/oj

Aarkrog, A., Baxter, M.S., Bettencourt, A.O., Bojanowski, R., Bologa, A., Charmasson, S., Cunha, I.,et al.: A Comparison of Doses from ^{137}Cs and ^{210}Po in Marine Food: A Major International Study. Journal of Environmental Radioactivity, 34, 69-90. 1997. https://doi.org/10.1016/0265-931X(96)00005-7

Alkhorayef, M., Hamza, Y., Sulieman, A., Salih, I., Babikir, E., Bradley, D.A.: Effective dose and radiation risk estimation in certain paediatric renal imaging procedures. Radiation Physics and Chemistry, https://doi.org/10.1016/j.radphyschem.2018.06.016. 2018.

Alonso-Hernández, C. M., Morera-Gómez, Y., Cartas-Águila, H., Guillén-Arruebarrena, A.: Atmospheric deposition patterns of ^{210}Pb and ^{7}Be in Cienfuegos, Cuba. Journal of Environmental Radioactivity, 138, 149-155. 2014. https://doi.org/10.1016/j.jenvrad.2014.08.023

Carvalho, F.P., Oliveira, J.M., Malta, M.: Radioactivity in Iberian Rivers with Uranium Mining Activities in their Catchment Areas. Procedia Earth and Planetary Science, 8, 48-52. 2014. https://doi.org/10.1016/j.proeps.2014.05.011

Cinelli, G., Gruber, V., De Felice, L., Bossew, P., Hernandez-Ceballos, M.A., Tollefsen, T., Mundigl, S., De Cort, M.: European annual cosmic-ray dose: estimation of population exposure. Journal of Maps, 13, 812-821. 2017. https://doi.org/10.1080/17445647.2017.1384934

De Cort, M., Dubois, G., Fridman, S.D., Germenchuk, M.G., Izrael, Y.A., Janssens, A., Jones, A.R., Kelly, G.N., Kvasnikova, E.V., Matveenko, I.I., Nazarov, I.M., Pokumeiko, Y.M., Sitak, V.A., Stukin, E.D., Tabachny, L.Y., Tsaturov, Y.S., Avdyushin, S.I.: Atlas of Caesium Deposition on Europe after the Chernobyl Accident. Office for Official Publications of the European Communities, Luxembourg. ISBN 92-828-3140-X, Catalogue number CG-NA-16-733-29-C. EUR 16733. 1998.

De Cort, M., Tollefsen, T., Marsano, A. & Gitzinger, C.: Environmental Radioactivity in the European Community 2004-2006. s.l.:s.n. 2004.

De Cort, M.; Sangiorgi, M.; Hernandez Ceballos, M. A.; Vanzo, S.; Nweke, E.; Tognoli, P. V.; Tollefsen, T. : REM data bank - Years 1984-2006. European Commission, Joint Research Centre (JRC) [Dataset] doi:10.2905/jrc-10117-10024 PID: http://data.europa.eu/89h/jrc-10117-10024 . 2007.

De Cort, M.; Sangiorgi, M.; Hernandez Ceballos, M. A.; Vanzo, S.; Nweke, E.; Tognoli, P. V.; Tollefsen, T. : REM data bank - Years 2006-2011. European Commission, Joint Research Centre (JRC) [Dataset] doi:10.2905/jrc-10117-10024 PID: doi:10.2905/de42f259-fafe-4329-9798-9d8fabb98de5 . 2012.

Eisenbud, M., Gesell, t., 1997. Environmental Radioactivity from Natural, Industrial and Military Sources. pp 656. Academic Press. Paperback ISBN: 9781493300419

Gabrieli, J., Cozzi, G., Vallelonga, P., Schwikowski. M., Sigl, M., Eickenberg, J., Wacker, L., Boutron, C., Gäggeler, H., Cescon, P., Barbante, C.: Contamination of Alpine snow and ice at Colle Gnifetti, Swiss/Italian Alps, from nuclear weapons tests. Atmospheric Environment 45, 587-593. 2011. https://doi.org/10.1016/j.atmosenv.2010.10.039

Guéguéniat, P., Germain, P., Métivier, H. (Eds.), Radionuclides in the Oceans. Publisher: Les Editions de Physique, pp. 220–231. 1996.

Imanaka, T., Hayashi, G., Endo, S.: Comparison of the accident process, radioactivity release and ground contamination between Chernobyl and Fukushima-1. Journal of Radiation Research, Volume 56, Issue suppl_1, 1 December 2015, Pages i56–i61. 2015. https://doi.org/10.1093/jrr/rrv074

InVS and AFSSET (Institut de Veille Sanitaire, Agence Francaise de Securite Sanitaire de L'environnement et du Travail): Estimating the health impact of environmental pollution and quantitative assessment of health risks, 2007. http://www.side.developpement-durable.gouv.fr/EXPLOITATION/DEFAULT/doc/IFD/IFD_REFDOC_0518539/estimation-de-l-impact-sanitaire-d-une-pollution-environnementale-et-evaluation-quantitative-des-ris

IAEA, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards, STI/PUB/1578, ISBN 978–92–0–135310–8, 2014

ICRP (International Commission on Radiological Protection) 1991a 1990; Recommendations of the International Commission on Radiological Protection. Annals of the ICRP, vol 21, nos 1–3. Pergamon Press, Oxford (ICRP publication 60).

Kaneyasu, N.; Ohashi, H.; Suzuki, F.; Okuda, T.; Ikemori, F.: Sulphate aerosol as a potential transport medium of radiocesium from the Fukushima nuclear accident. Environmental Science & Technology, 46 (11), 5720 – 5726. 2012. DOI: 10.1021/es204667h

Livingston, H.D., Povinec, P.P.: Anthropogenic marine radioactivity. Ocean and Coastal Management, Volume 43, Issues 8–9, 2000, Pages 689-712, https://doi.org/10.1016/S0964-5691(00)00054-5

Lozano, R.L.,Hernández-Ceballos, M.A., San Miguel, E.G., Adame, J.A., Bolívar, J.P., Meteorological factors influencing the ^{7}Be and ^{210}Pb concentrations in surface air from the southwestern Iberian Peninsula. Atmospheric Environment, 63, pp. 168-178. 2012. https://doi.org/10.1016/j.atmosenv.2012.09.052

Magnoni, M., Environmental Radioactivity and Radioecology. In Physical Agents in the environment and workplace-Noise and vibrations, electromagnetic fields and Ionizing Radiations (Edited by Gaetano Licitra, Giovanni d'Amore, Mauro Magnoni). Taylor and Francis Group, LLC, 2018.

Merz, S., Shozugawa, K., Steinhauser, G.: Effective and ecological half-lives of ^{90}Sr and ^{137}Cs observed in wheat and rice in Japan. Journal of Radioanalytical and Nuclear Chemistry, March 2016, Volume 307, Issue 3, pp 1807–1810. 2016. https://doi.org/10.1007/s10967-015-4352-6

Nies, H., Nielsen, S.P., Radioactivity in the Baltic Sea. Conference of International Symposium on Radionuclides in the Oceans, France. 1996

Nweke, E. P. et al.: REM Data Submission Tool User Guide Release 2.0, s.l.: s.n. 2015.

Ogundarea, F.O., Adekoya, O.I.: Gross alpha and beta radioactivity in surface soil and drinkable water around a steel processing facility. Journal of Radiation Research and Applied Sciences. 8, 411-417. 2015. https://doi.org/10.1016/j.jrras.2015.02.009

Povinec, P.P., Bailly du Bois, P., Kershaw, P.J., Nies, H., Scotto, P.: Temporal and spatial trends in the distribution of 137Cs in surface waters of Northern European Seas—a record of 40 years of investigations. Deep Sea Research Part II: Topical Studies in Oceanography, 50, 2785-2801. 2003. https://doi.org/10.1016/S0967-0645(03)00148-6

UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation): Sources and Effects of Ionizing Radiation. Report to the General Assembly Annex B: Exposures of the Public and Workers from Various Sources of Radiation. United Nations, New York. 2008.

WHO/FAO (World Health Organization & Food and Agriculture Organization of the United Nations). (2006(. Food safety risk analysis: a guide for national food safety authorities. Geneva: World Health Organization. http://www.who.int/iris/handle/10665/43718.

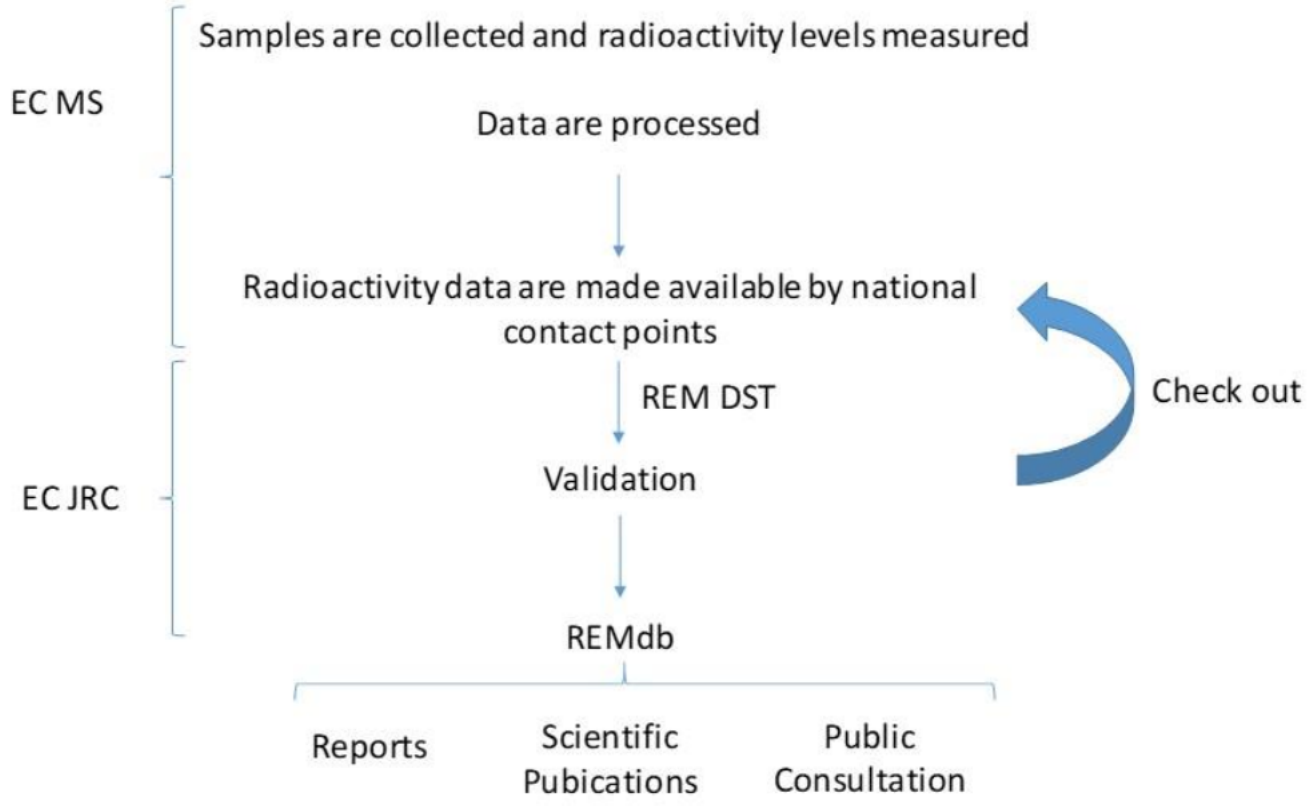

Figure 1: Flow of data to be stored in the REMdb.

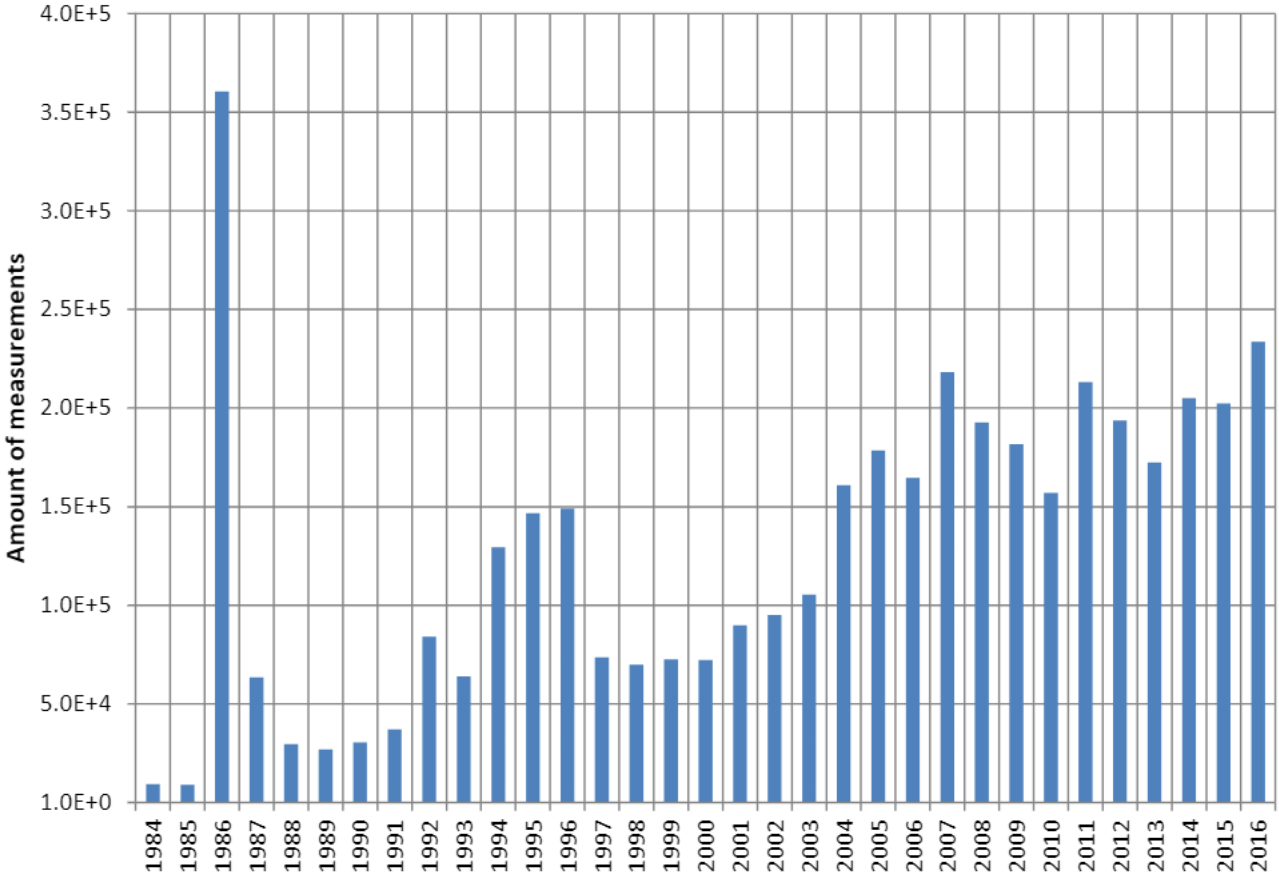

Figure 2. Amount of single measurements stored in the REMdb.

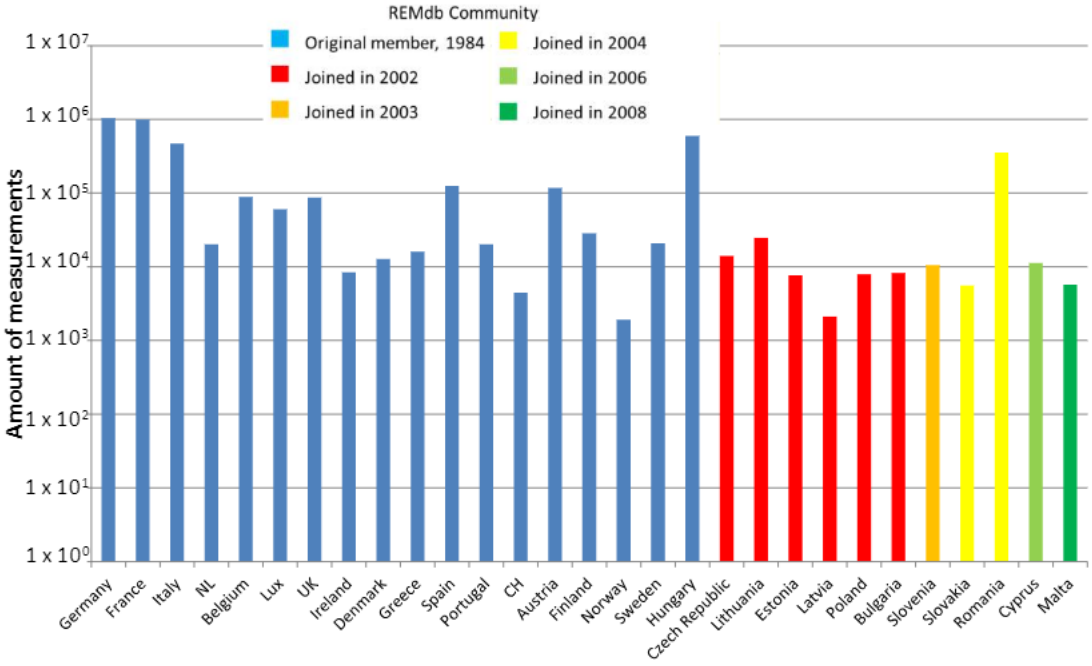

Figure 3. Country participating to REMdb according to their year of joining and amount of measurements stored in REMdb from each country.

Locations	Name	Samples	Sample Type	Measurements	Apparatus
	Catchment		Sample Treatment		Nuclide
	NUTS Code		Begin Date/Time		Activity Value
	Latitude		End Date/Time		Measurement Unit
	Longitude		Laboratory		Value Type
	Altitude				Uncertainty Value
	Coordinate Accuracy				Uncertainty Type
					Uncertainty Unit

Table 1. Minimum requirements associated with each data stored in REMdb

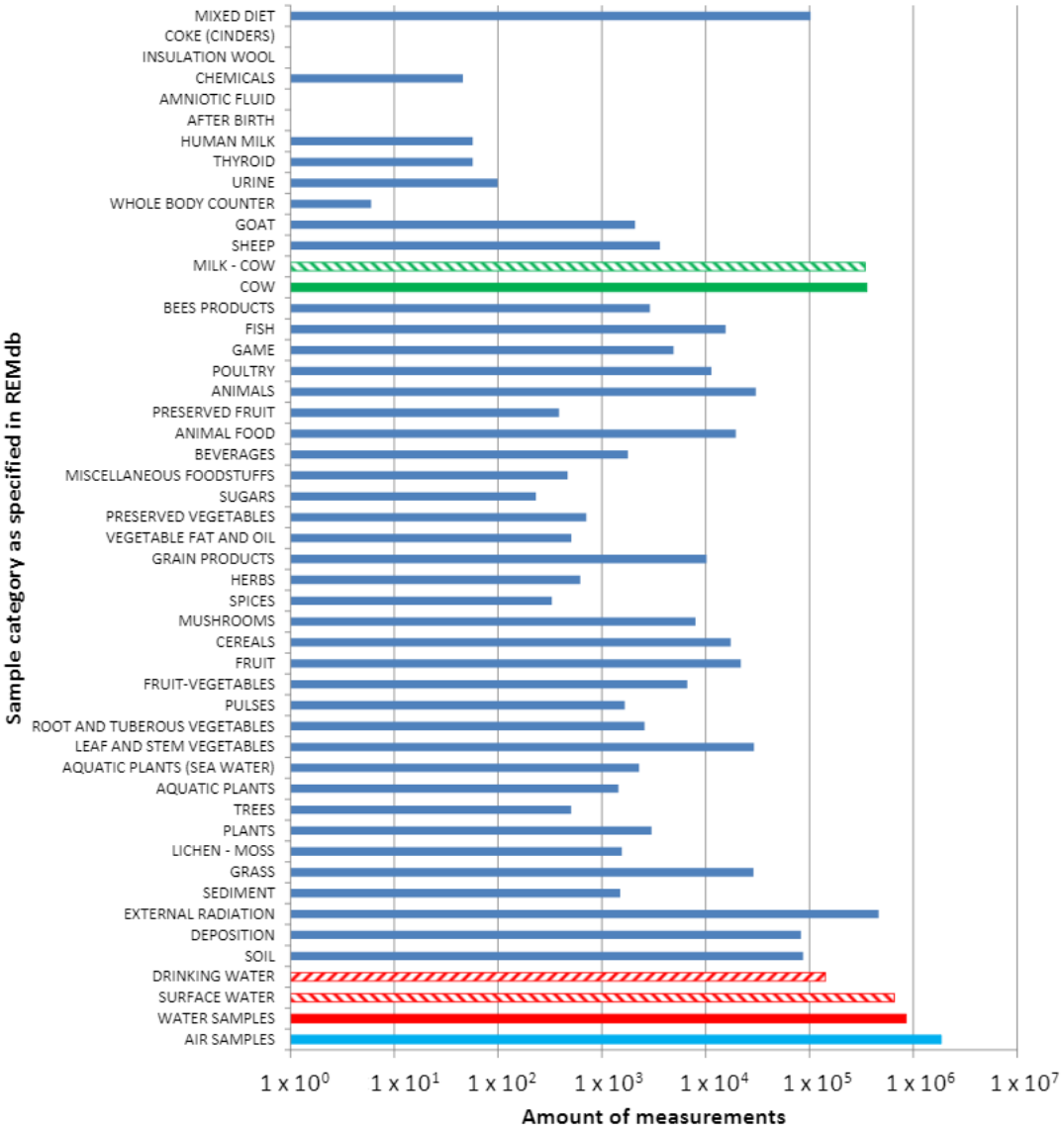

Figure 4. Amount of measurements per sample type as specified in REMdb (logarithmic scale, subtypes Surface water and Drinking water are included in type Water samples, subtype Milk-Cow is included in type Cow).

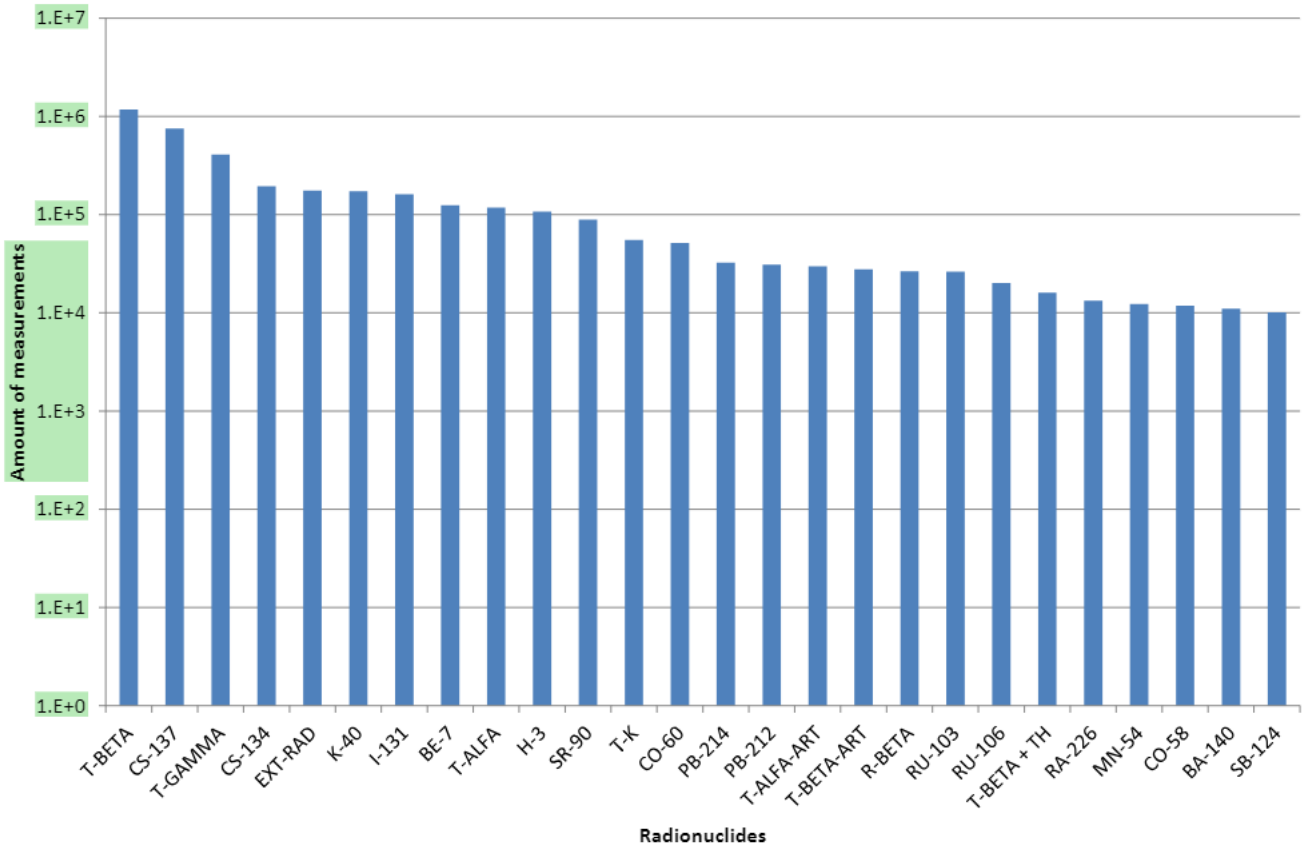

Figure 5. Amount of single measurements grouped by radionuclide stored in REMdb; the figure shows just those with a number of measurements above 1 x 10^4.

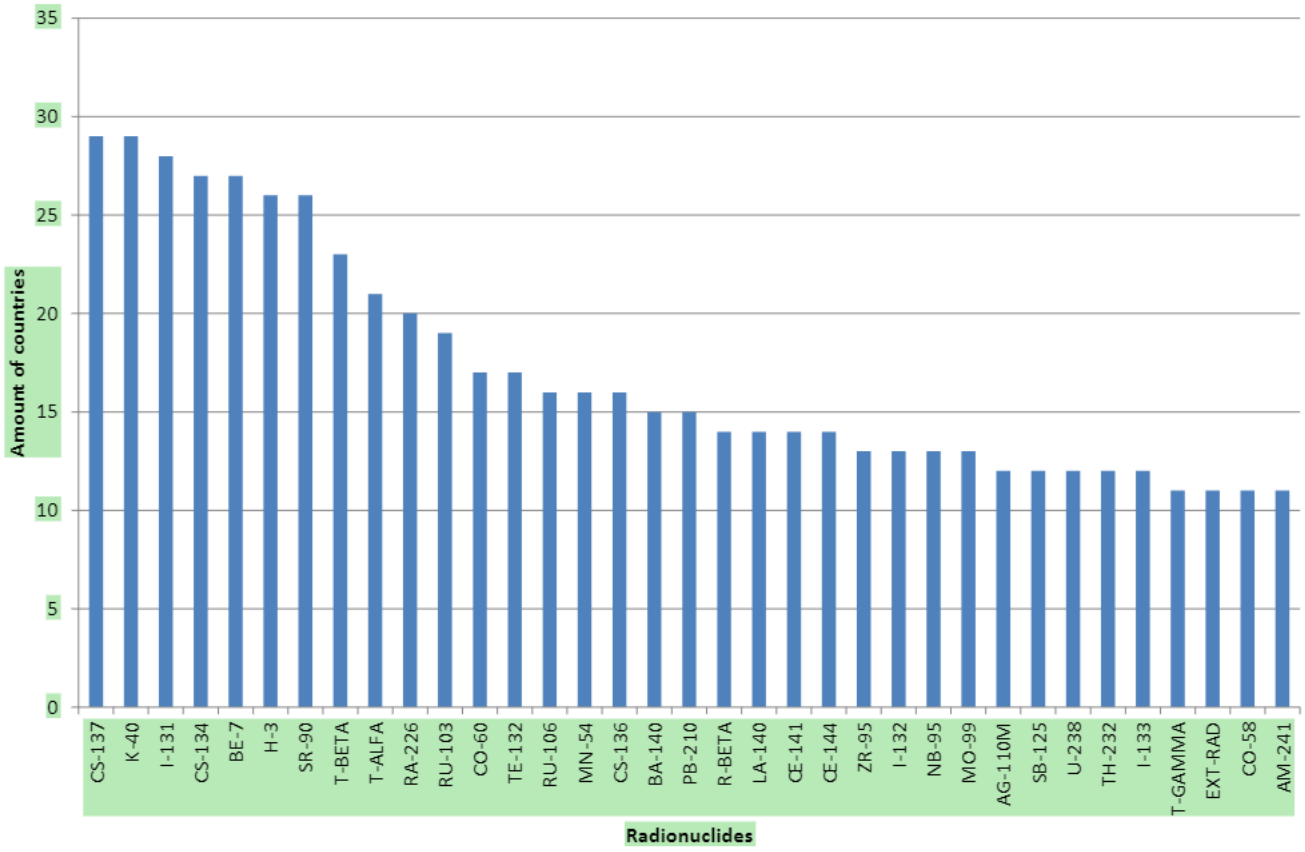

Figure 6. Amount of countries providing information of a certain radionuclide to REMdb; the figure shows just those radionuclides with at 10 countries reporting them.

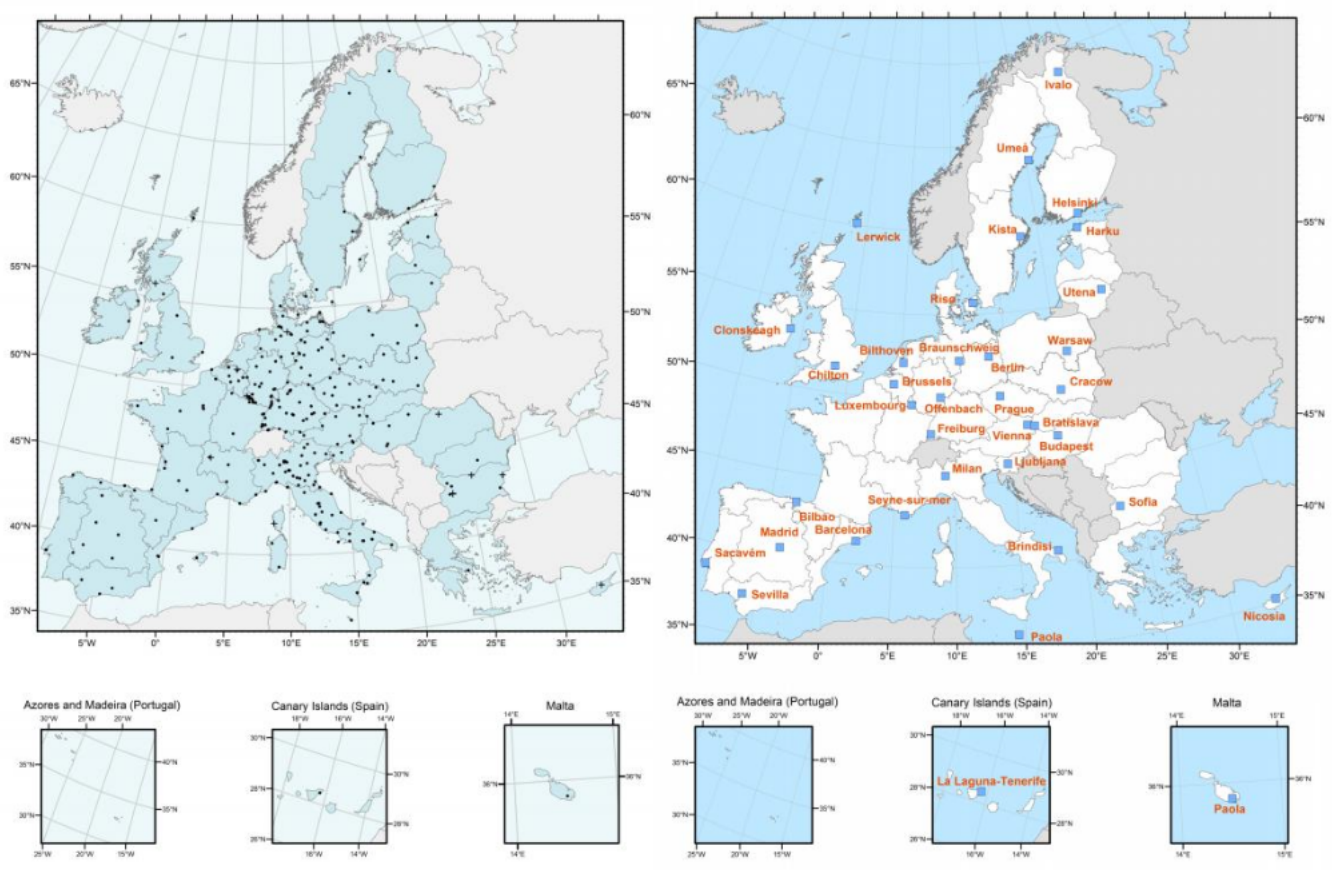

Figure 7. Example of sampling locations of dense (left) and sparse (right) network for ^{137}Cs as airborne particulates, year 2011.

Sampling Media	Radionuclide category	
	Dense network	Sparse network
Airborne particulates	^{137}Cs, gross beta	^{137}Cs, ^{7}Be
Surface water	^{137}Cs, residual beta	^{137}Cs
Drinking water	Tritium, ^{90}Sr, ^{137}Cs	Tritium, ^{90}Sr, ^{137}Cs
Milk	^{137}Cs, ^{90}Sr	^{137}Cs, ^{90}Sr, ^{40}K
Mixed diet	^{137}Cs, ^{90}Sr	^{137}Cs, ^{90}Sr, ^{14}C

Table 2: Sample types and measurements as recommended in (2000/473/Euratom).

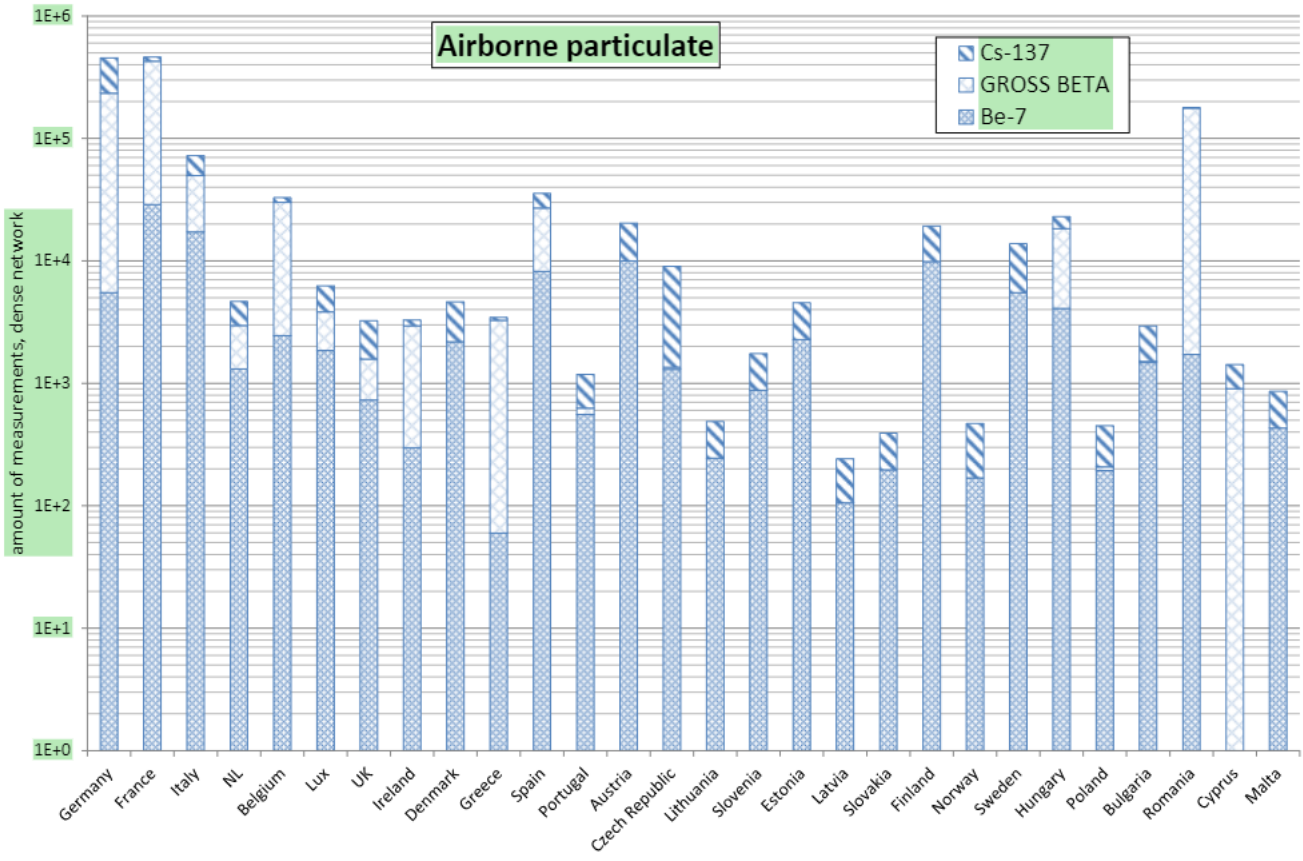

Figure 8. Total amount of measurements in REMdb (dense network) for sample type airborne particulates, ^{137}Cs, total beta and ^{7}Be, by country as recommended in (2000/273/Euratom).

5

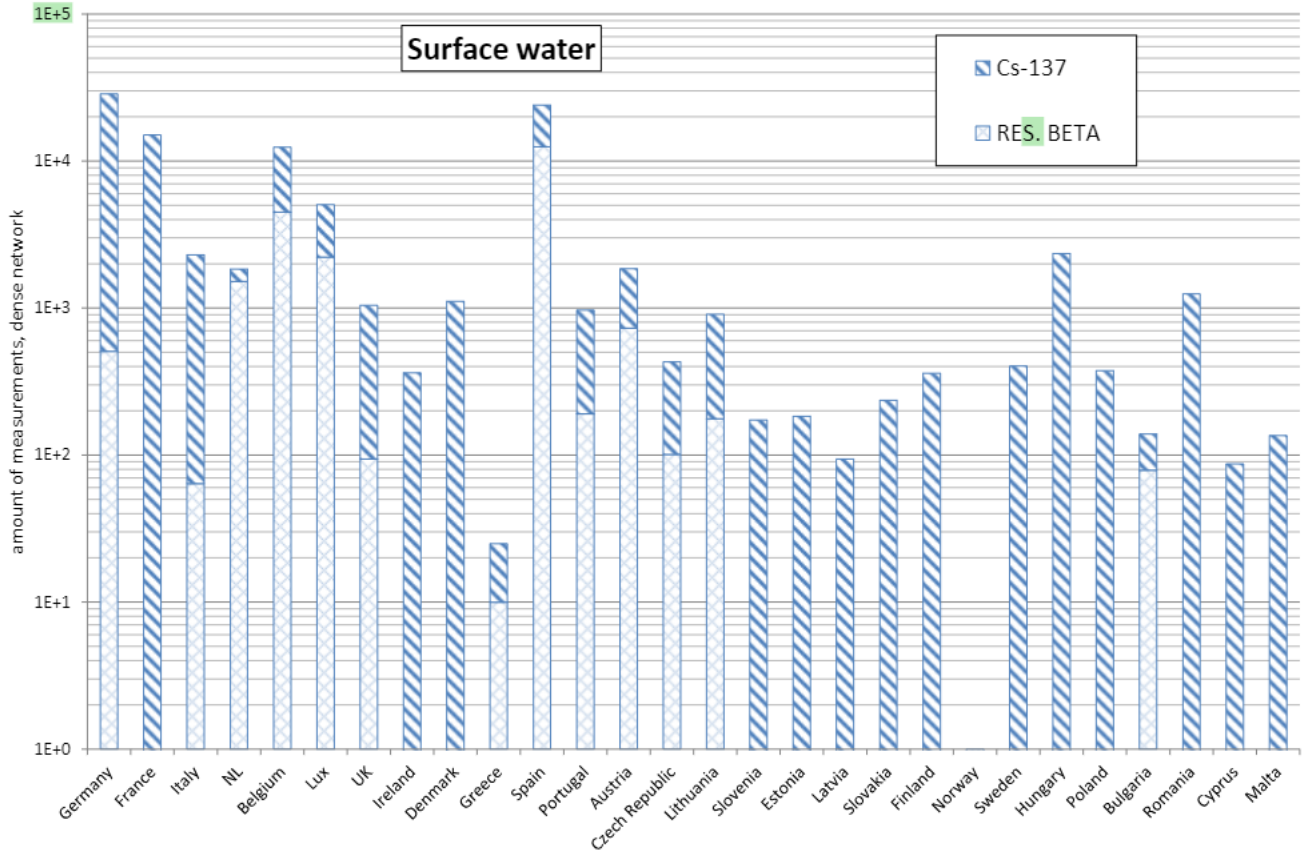

Figure 9a. Amount of measurements in REMdb (dense network) for surface water, by country, as recommended in (2000/473/Euratom).

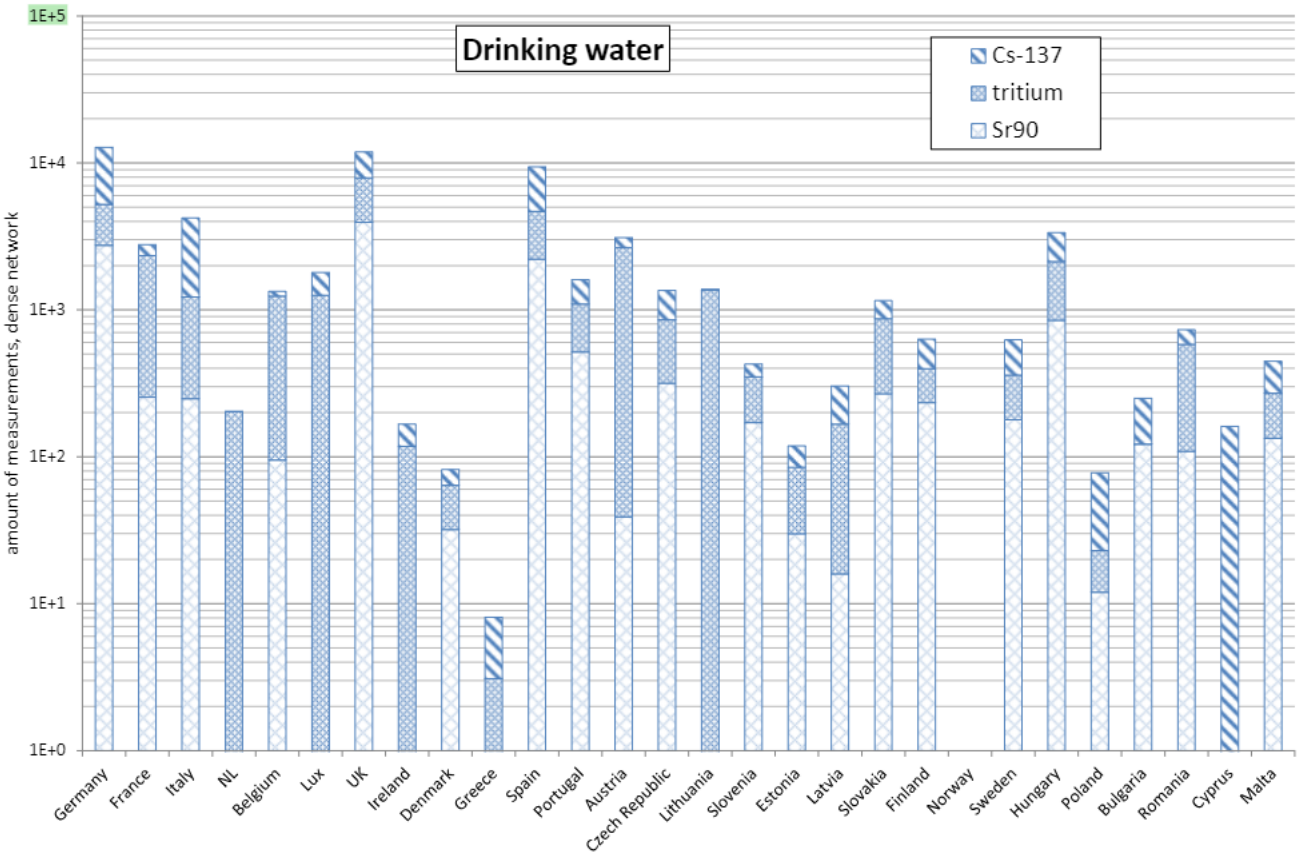

Figure 9b. Amount of measurements in REMdb (dense network) for drinking water, by country, as recommended in (2000/473/Euratom).

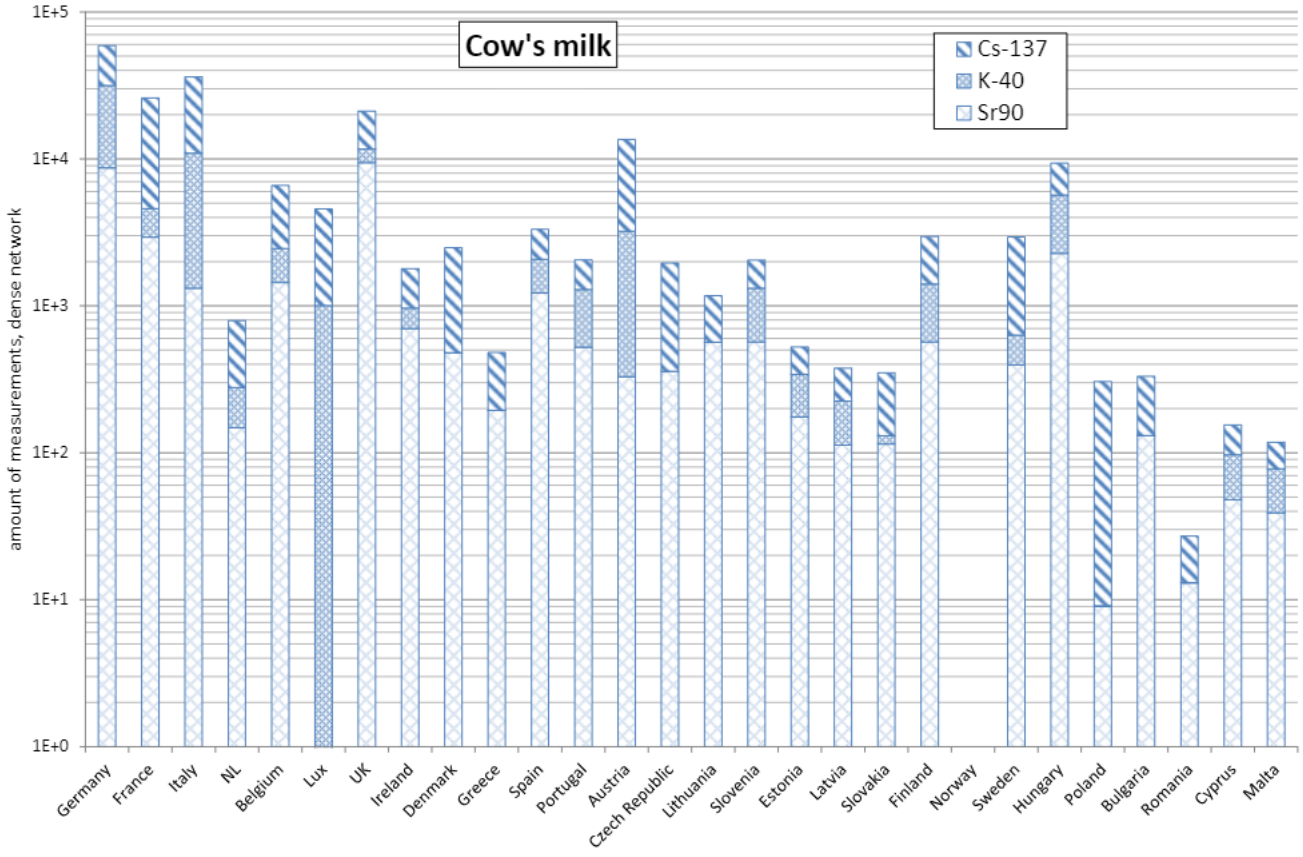

Figure 10. Amount of measurements in REMdb (dense network) for sample type cow's milk, ^{137}Cs, ^{40}K and ^{90}Sr, by country, as recommended in (2000/473/Euratom).

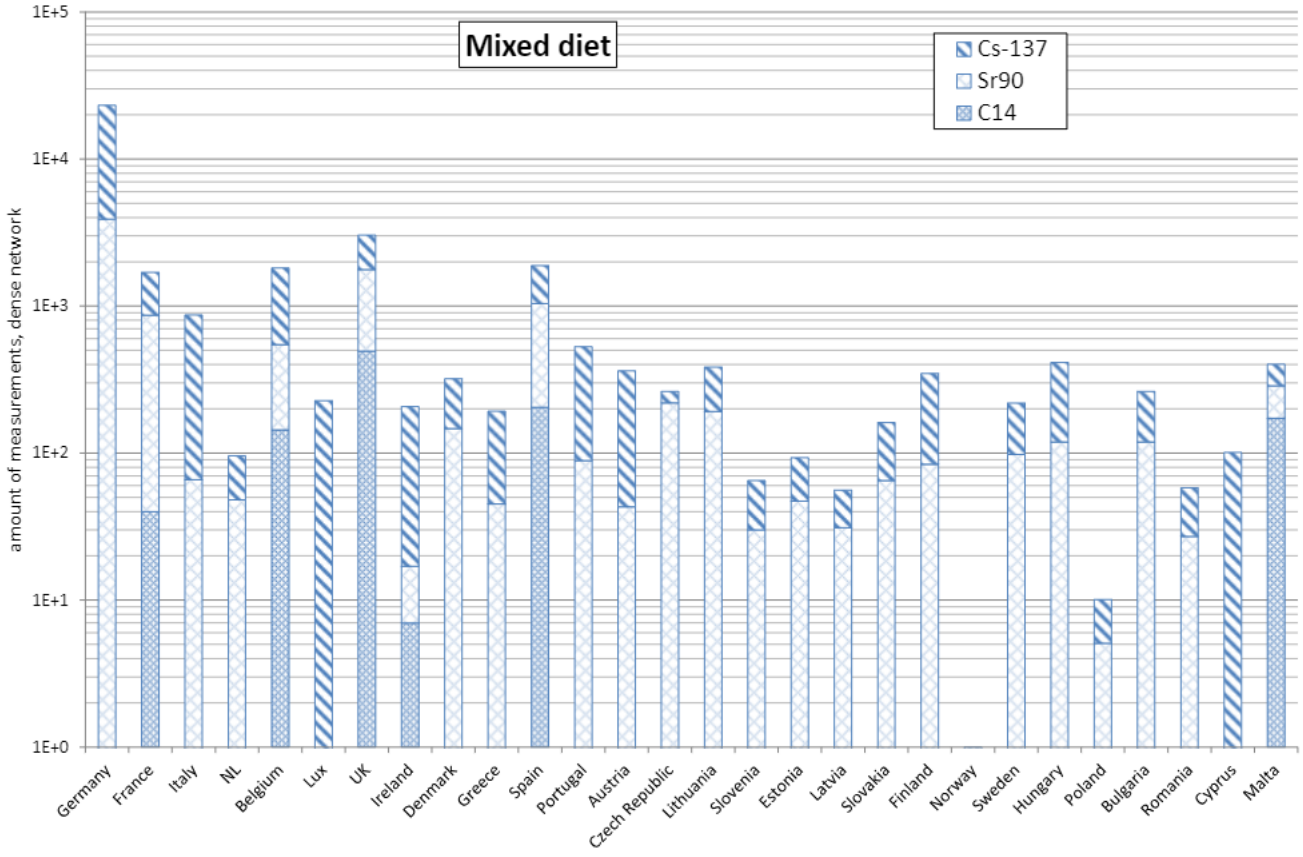

Figure 11. Amount of measurements in REMdb for sample type mixed diet, ^{137}Cs, ^{90}Sr and ^{14}C, by country, as recommended in (2000/473/Euratom).