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Surveillance of Radioactivity in the Environment

The Belgian Society for Radiation Protection organised on 22 October 2021 a scientific meeting on the Surveillance of Radioactivity un the Environment. The meeting took place in Louvain-la-Neuve.

This publication compiles five texts that were provided after the meeting by the lecturers who had made presentations at the scientific meeting.

The BVSABR

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Surveillance of Radioactivity in the Environment

CONTENT

Radiological monitoring of the environment

Example of monitoring in Luxembourg

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Abstract

In Luxembourg, the radiological monitoring of the environment is the responsibility of the Radiation Protection Division (DRP) of the Health Directorate. Its areas of expertise are the protection against ionizing and non-ionizing radiation, the nuclear safety and the safety of radioactive waste management.

Two radiation measurement networks were created in 1983. These are composed of a network of measurements and automatic alerts (remote monitoring) and a network for taking samples in the environment (air, water, soil, foodstuffs, …) which are analysed a posteriori in the DRP-laboratory.

These two networks are complementary and ensure continuous monitoring of background radiation of the national territory, enabling the detection of uncontrolled and accidental releases from nuclear installations in neighbouring countries, in Europe or worldwide and herewith provide data and support to national authorities in the event of a nuclear emergency. Increases in artificial radioactivity have been monitored following the accidents of Chernobyl in 1986 and of Fukushima-Daiischi in 2011. Some examples of those results are presented.

Keywords: monitoring, measurement, EPR, early warning, environmental samples

Surveillance radiologique de l'environnement

Exemple de surveillance au Luxembourg

Organisation et responsabilités

Au Luxembourg, la surveillance radiologique de l'environnement (SRE) est à la charge de la Division de la Radioprotection (DRP). Ses domaines de compétence sont la protection contre les rayonnements ionisants et non ionisants, la sécurité nucléaire et la sécurité de la gestion des déchets radioactifs.

La DRP fait partie depuis la fin de l'année 2021 du nouveau pôle « infections et environnements » du département médical et technique de la Direction de la santé qui relève de l'autorité du Ministre de la santé. La DRP est elle-même subdivisée en 5 services parmi lesquels se trouvent le service des urgences et équipements et le service d'analyses radiologiques (SAR), un laboratoire. Du fait de leurs missions, ces deux services sont particulièrement impliqués dans la SRE au Luxembourg respectant ainsi l'engagement du pays au Traité EURATOM et notamment l'application des articles 35 et 36.

Sources de rayonnement ionisants

Au Luxembourg, la population est soumise à des doses efficaces annuelles estimées à 5.17 mSv. En comparaison avec les pays frontaliers, les valeurs des doses efficaces sont de 4.5 mSv pour la France (IRSN, 2021 site internet) et d'environ 4 mSv en Belgique (AFCN, 2015 site internet). Le chiffre élevé pour le Luxembourg provient du diagnostic médical. En effet, la fréquence des examens Computer Tomography (CT scanners) par habitant est l'une des plus élevées d'Europe : 1ère place en 2015 avec plus de 207 examens scanners pour 1000 habitants.

Dans le détail, deux tiers des expositions des habitants aux rayonnements ionisants ont une origine naturelle. Ils sont tout d'abord liés à la radioactivité dans l'air, comme le radon, notamment au nord du pays, auquel il faut rajouter le rayonnement cosmique, le rayonnement terrestre ou tellurique et le rayonnement du corps humain. Les sources artificielles ont une origine soit médicale avec les examens d'imagerie médicale comme la radiologie et la médecine nucléaire présente dans quatre établissements hospitaliers, soit non médicale issue d'applications du domaine industriel ou encore liée aux retombées d'essais nucléaires et accidents.

Le Luxembourg ne possède pas d'installations nucléaires ou de sites de productions de radionucléides.

Législation

Au Luxembourg, la SRE est principalement basée sur :

- le règlement grand-ducal du 07 juillet 2017 relatif à la qualité des eaux destinées à la consommation humaine, transposition de la directive 2013/51 ;
- la loi du 28 mai 2019 et le règlement du 1er août 2019 relatifs à la radioprotection, transposition de la directive BSS 2013/59.

Réseaux de mesures

Les 2 services évoqués précédemment ont élaboré des réseaux pour surveiller l'environnement.

Service des urgences et équipements

Historique

Pour faire face à une situation d'urgence nucléaire et pour pouvoir apprécier l'impact radiologique d'une telle situation, le Luxembourg a commencé dès 1983 à installer un réseau de mesures et d'alertes automatiques (télésurveillance) sur son territoire national. Dans les faits, l'installation d'un nouveau réseau de mesure sur le territoire luxembourgeois a été surtout liée à la décision des autorités françaises de construire une centrale nucléaire non loin de la frontière luxembourgeoise.

A sa création, le réseau est constitué de huit balises (sondes de type Geiger Müller ou GM) implantées le long de la frontière française. Le tout fut complété d'un détecteur NaI dans les eaux de la Moselle à Schengen en 1984.

Après l’accident de Tchernobyl en 1986, une extension du réseau couvrant tout le territoire national a été décidée en installant 10 balises supplémentaires (sondes GM, de 1991-1993) et 2 balises aérosols à filtre fixe (1990, 2002)

D'un commun accord avec la France, une station de mesure commune FR-LU a été mise en place à Roussy-Le-Bourg (FR) (Téléray et aérosols; mise en service janvier 1996; remplacée en 2017).

En 2001, le plan d'action menace terroriste a conduit à l’installation d'une balise et d'un échantillonneur "eau" à l'entrée de l'usine de production d'eau du lac d'Esch/Sûre. Cette dernière assure les deux-tiers de la production d’eau potable du pays.

Plus récemment, le retour d'expérience des exercices d'accidents nucléaires a conduit à acquérir des balises mobiles, afin de créer un maillage plus fin dans les régions potentiellement touchées.

Concept du réseau automatique

La finalité du réseau est :

- d’assurer une surveillance en continu de la radioactivité ambiante et du bruit de fond du rayonnement naturel,
- de veiller sur la centrale nucléaire la plus proche de la frontière nationale par le biais d'un maillage de stations fixes espacées de ± 10 km et situées à des rayons de ± 10; 20; 30; 40; 50; 80 km (fig.1),
- d’assurer une couverture du territoire national, en vue de détecter des rejets incontrôlés et accidentels d'installations nucléaires dans les pays voisins, en Europe ou dans le monde,
- d’apporter un support aux autorités nationales en cas d'urgence nucléaire.

Composition du réseau

Le réseau actuel est en cours de renouvellement. Il est composé de :

- 18 balises fixes du type GM,
- 2 stations de collecteurs d'aérosols Type (alpha/bêta), radon,
- 1 station de collecteurs d'aérosols de haut volume,
- 1 station (type alpha/bêta et spectroscopie gamma) plus dédiée à la surveillance de la centrale nucléaire de Cattenom,

- 2 stations de surveillance des eaux superficielles (type NaI) assurant le contrôle a) du lac de la Haute–Sûre (production d'eau potable) à Esch/Sûre et b) les rejets liquides ayant lieu dans la Moselle en amont de Schengen, complétées d'échantillonneurs automatiques,
- 10 balises mobiles pouvant assurer, selon le besoin, un maillage plus fin dans une région ou zone affectée et lors d'incidents locaux (accident de transport, industrie, actes de malveillance, …),
- 2 stations météorologiques.

Des systèmes embarqués du type MONA (spectre des dépôts) ou MobRad (GM) permettent de compléter ce réseau en cas de besoin.

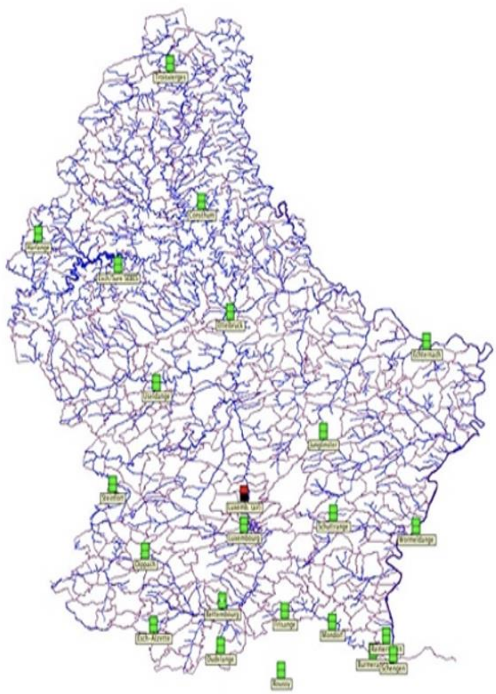

Fig. 1 : Cartes de localisation des balises et stations au Luxembourg sur la plateforme NMC.

Centralisation des données

Les données des instruments de mesure sont envoyées avec un pas de temps horaire à la centrale « network monitoring center (NMC)", une plateforme permettant de gérer et de visualiser les données sous forme de tableaux ou de graphiques. L'ensemble des informations est stocké dans une base de données.

Accessibilité des données

Les résultats des mesures sont aussi envoyés sur le site de la Commission européenne, EUropean Radiological Data Exchange Platform (EURDEP). C'est l'option choisie actuellement par le Luxembourg pour la diffusion et la visualisation des données de ce réseau. Cette plateforme est accessible au public par le lien : https://remon.jrc.ec.europa.eu/ .

Observations

En fonctionnement de routine, le réseau détermine principalement l'exposition naturelle aux rayonnements auxquels l'homme est constamment exposé. Ce sont, par exemple, des substances radioactives présentes partout dans le sol comme l'uranium, le thorium et le potassium 40.

Le débit de dose équivalent ambiant est donné en µSv/h. Au Luxembourg, le débit de dose naturel varie de 0.05 à 0.18 µSv/h en moyenne mensuelle, selon les conditions locales (fig.2). Ce débit peut varier en fonction des teneurs en radon, un élément de la chaîne de désintégration naturelle de l'uranium 238. Ce gaz se diffuse depuis le sol dans l'air. Lors de précipitations, le lessivage de ses produits de filiations peut alors entraîner des pics brutaux.

Service d'analyses radiologiques

Historique

Le SAR a été créé en 1983 en parallèle à la mise en place du réseau automatique de mesures. Ce service est un laboratoire dédié essentiellement à l'analyse des échantillons prélevés par le réseau de prélèvements. Historiquement, la création de ce service relevait de l'application de l'article 35 du Traité EURATOM portant sur la surveillance de la radioactivité dans l'environnement et dans la chaîne alimentaire. Il faut noter que depuis sa création, des programmes sont venus compléter cette surveillance environnementale comme avec les eaux potables, le radon dans l'air et la préparation à une situation d'urgence radiologique ou nucléaire.

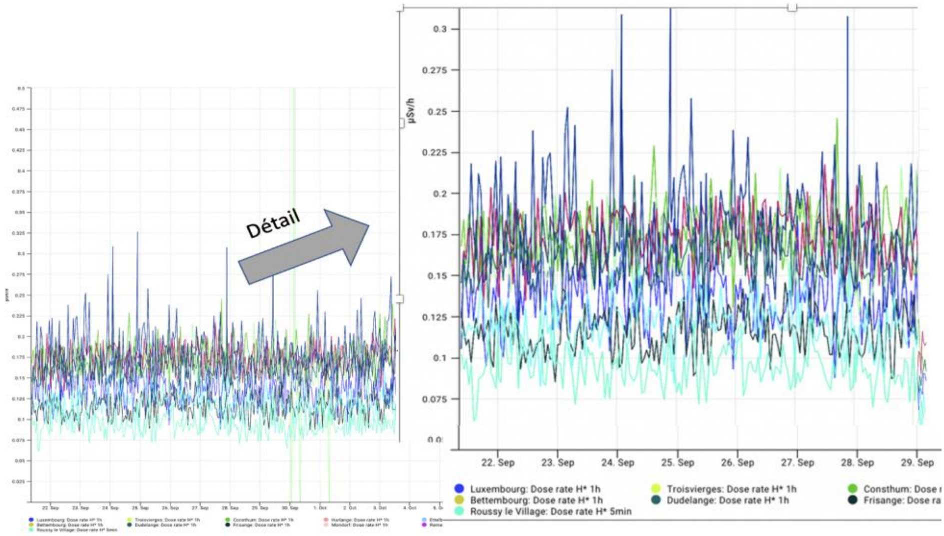

Fig. 2 : Exemple de débits de dose relevés dans les stations de mesure du réseau luxembourgeois.

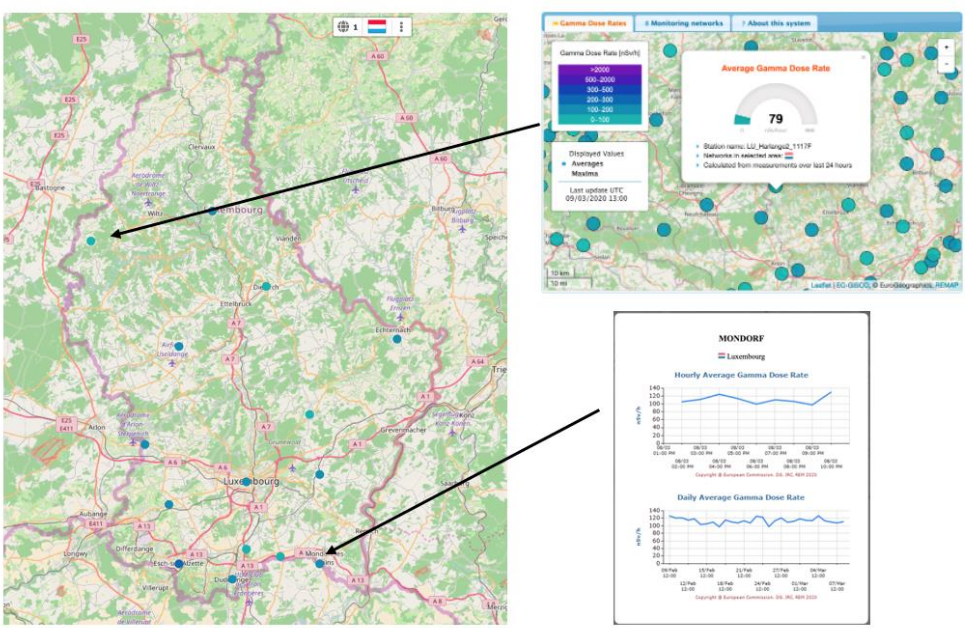

Fig. 3 : Stations automatiques luxembourgeoises sur le site d'EURDEP (à droite : détail des informations accessibles pour deux positions).

Spécificité

C'est le seul laboratoire de ce type au Luxembourg. Il est accrédité ISO/IEC 17025 depuis 2010 par l'Organisme Luxembourgeois d'accréditation et de Surveillance (OLAS).

Dans le cadre de la SRE, un minimum de quinze points sont contrôlés régulièrement dans différents compartiments (air, eau, sol, denrées alimentaires,..).

En 2021, le nombre d'échantillons réceptionnés atteignait:

- 334 échantillons issus de l'environnement,
- 165 échantillons issus de l'alimentation,
- 214 échantillons d'eau potable.

Equipements

Le SAR dispose de cinq spectromètres gamma (fig. 4), de trois compteurs proportionnels (fig. 5), d'un compteur en scintillation liquide (fig.6), d'un

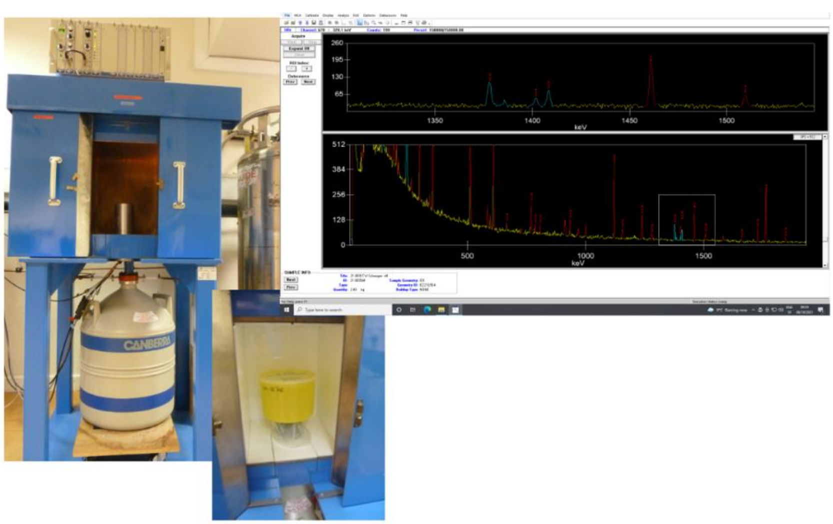

Fig. 4 : Spectromètre gamma avec un récipient de comptage de type Marinelli contenant de l'eau et spectre de mesure.

Fig. 5 : Compteurs proportionnels et échantillons en préparation. Deux filtres air avant et après dépôts d'aérosols (photo de droite).

Fig. 6 : Compteur en scintillation liquide pour la mesure du tritium ou du radon dans l'eau.

spectromètre alpha et de quatre moniteurs radon. Ces instruments de mesure donnent un bon aperçu du niveau de radioactivité naturelle et artificielle dans les échantillons analysés.

Les activités relevées aujourd'hui pour les radionucléides artificiels sont très faibles et généralement inférieures aux limites de détection.

Evènements radiologiques importants

La SRE a permis de suivre les élévations de la radioactivité artificielle lors des accidents de Tchernobyl ou de Fukushima-Daiischi. Les graphiques suivants montrent les résultats de ces observations notamment dans le lait ou les champignons des bois après 1986 ou dans les aérosols et l'herbe en 2011.

Tchernobyl

Lait

Le lait, aliment de base, profite d'une attention particulière. En 1986, des collectes ont eu lieu dans une laiterie et des fermes. Malgré tout, l'intérêt est porté plutôt sur les résultats de la laiterie car les échantillons sont issus d'un mélange de laits d'origines géographiques variées ce qui donne une bonne représentation globale à l'échelle du pays (fig. 7).

Les valeurs du césium 134 et du césium 137 montrent deux pics dans les graphiques suivants. Le premier pic est observé en mai 1986 lors du passage du nuage radioactif sur le pays. Le deuxième pic est expliqué par un fourrage contaminé.

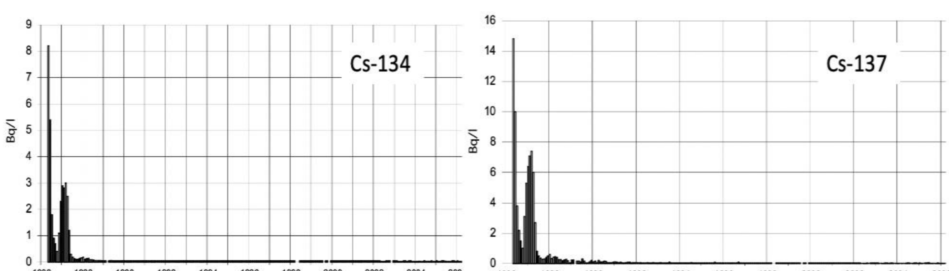

Fig. 7 : Activités volumiques en césiums dans les laits issus d'une laiterie luxembourgeoise

Dans les deux graphiques, les valeurs baissent rapidement et restent en dessous de la limite de report.

Champignons des bois

Certaines espèces de champignons sont très sensibles aux contaminations radioactives au sol, notamment le bolet bai qui peut avoir un taux en césium particulièrement élevé. Le graphique suivant (fig.8) montre les valeurs relevées dans les échantillons mesurés au SAR.

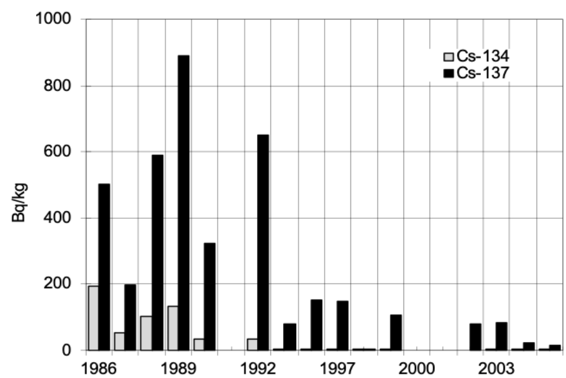

Fig. 8: Activités massiques en césiums dans des champignons des bois après 1986.

En 1986, seulement une partie du césium 137 dans les champignons était due aux retombées radioactives provenant de Tchernobyl. En effet, dans un échantillon de bolet bai récolté en 1985, le taux en césium 137 s'élevait à 86 Bq/kg. Cette contamination provenait des retombées radioactives consécutives aux essais d'armes nucléaires atmosphériques.

Fukushima-Daiischi

Aérosols

Deux stations de prélèvements d’aérosols ont été sélectionnées pour suivre les rejets de l’accident de Fukushima-Daiischi. Ce sont les stations placées à la ville de Luxembourg et plus précisément à la Villa Louvigny, au centre, et à l’aéroport du Findel.

Les premières traces de radioactivité issues des rejets de la centrale nucléaire sont apparues entre le 23 mars et le 24 mars 2011. C'est d'abord l'iode 131 particulaire qui a été mesuré avec une valeur de 0.00015 Bq/m^3 (0.151 mBq/m^3) en moyenne sur un jour. Un pic de concentration de 0.00162 Bq/m^3 a été relevé entre le 28 et le 30 mars à la station Villa Louvigny (fig.9).

Par comparaison, l'iode particulaire 131 a tout d'abord été détecté en Suède et en Finlande les 22 et 23 mars avec des valeurs de 0.3 à 1 mBq/m^3. En France, il a été mis en évidence sur la période de prélèvement du 21 au 24 mars dans une station située dans le Massif Central.

D'autres éléments issus des rejets de la centrale de Fukushima-Daiischi ont également été mesurés. C'est à partir de la période du 28-29 mars pour la station Villa et de la période 22-29 mars pour la station du Findel que des traces de césium 137 et 134 ont été détectées. Le haut volume de prélèvement de l'air de la station du Findel (750 à 800 m^3/h) explique que des éléments tels que l'iode 132, le tellure 132 ou encore le césium 136 aient été également trouvés. Toutefois, ces valeurs sont très basses (< 1 mBq/m^3).

Végétaux : herbe

En fonction de la météo, la contamination des végétaux dont l'herbe, varie. Elle augmente avec la pluie.

Des traces d'iode 131 sont mesurées dès le 1er avril 2011 sur le premier prélèvement de Schengen. C'est la valeur la plus élevée des 5 prélèvements effectués. Les deux autres radionucléides, le césium 134 et le césium 137, ont également été mesurés avec des activités dans l'ensemble plus faibles (fig.10). La variation des concentrations observées est à mettre en relation avec l'hétérogénéité des précipitations.

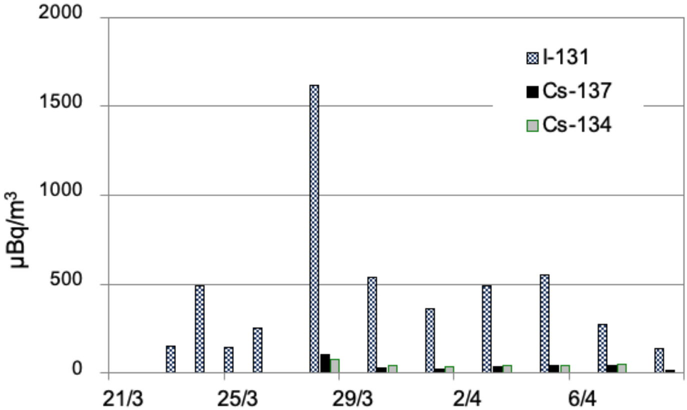

Fig. 9: Aérosols à la station Luxembourg-Villa après Fukushima-Daiischi en 2011

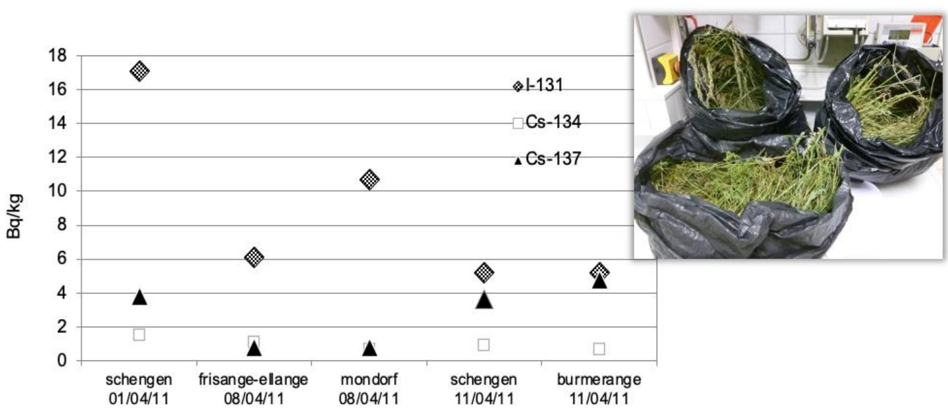

Fig. 10: Activités massiques des radionucléides observés dans des herbes après Fukushima-Daiischi

Information du public

Une partie des données de la SRE, recueillies par le SAR, sont publiées dans un rapport mensuel accessible sur le site du Ministère de la Santé : www.sante.lu ou sur le site de la Commission européenne : remap.jrc.ec.europa.eu/Routine.aspx.

The inventory of the natural radioactivity in Belgium

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Abstract

Natural radiation accounts for about 60% of the yearly average exposure of the Belgian population and involves several components. Radon is the main source of exposure to natural radiation, but some industrial activities may also deal with materials and residues containing an enhanced activity concentration in natural radionuclides compared to background activity levels in Belgian soils. These so-called "NORM industries" may impact the environment and are monitored within FANC's national radiological surveillance program. Radiological surveillance also includes the follow up of the natural radioactivity of building materials. As natural radionuclides are generally associated to other, non-radioactive contaminants, FANC also set up collaborations with relevant environmental agencies.

Keywords: monitoring, NORM industry, building materials, legacy sites

[1] Current affiliation : European NORM Association (ENA)

1. Introduction

Natural radiation accounts for about 60% of the yearly average exposure of the Belgian population. This corresponds to 2.4 mSv/y, the other 40% being essentially related to medical exposure [1]. Exposure to natural radiation has several components:

- Exposure to cosmic radiation (0.3 mSv/y);
- External exposure to terrestrial radiation (0.4 mSv/y);
- Ingestion of natural radionuclides present in drinking water and foodstuffs (0.3 mSv/y);
- Inhalation of radon and its progenies (1.4 mSv/y);

Radon is the main source of exposure to natural radiation. Its distribution in Belgium is strongly correlated to the geology of the soil and sustained measurement campaigns have allowed to establish a precise mapping of Belgian radon-prone areas [2-6].

Natural radiation is emitted by the radionuclides in the decay chains of uranium and thorium and by the potassium isotope K-40. While typical background activity concentration for the uranium and thorium series in Belgian soils are in the range of a few tens of Bq/kg [2,7], some minerals may contain an enhanced concentration of natural radionuclides. When this concentration is not negligible from a radiation protection point of view, one speaks about Naturally Occurring Radioactive Material or “NORM”.

Several industrial activities may involve NORM: a typical example is the processing of phosphate ores which often contain an enhanced concentration in either uranium or thorium (uranium concentration in sedimentary phosphate ores from Morocco is typically 300 – 500 ppm, which corresponds to 3 to 5 Bq/g of U-238). Moreover, not only the raw materials can be a source of NORM but the industrial processes themselves may further concentrate the natural radionuclides in the residues or products of the processes. The uranium and thorium decay chains are in secular equilibrium in the earth’s crust and in unprocessed minerals. This secular equilibrium may however be broken when raw materials containing natural radionuclides are processed chemically and/or physically. Consequently, the type of natural radionuclides and their activity concentrations in NORM are very variable from one industrial process to the other.

The impact of NORM on the environment has been acknowledged for decades: in the 1960s already, R. Kirchmann and his collaborators [8] had identified the impact of the radium discharges from the Belgian phosphate industry on the environment. Additional studies in the 1990s and 2000s have demonstrated the extent of activities involving NORM in Belgium [9-12]. Following the implementation of the former European BSS (Directive 1996/29/Euratom), the concept of '*work activity involving natural radiation sources*' was introduced in Belgian regulations through the publication of the Royal Decree of 20 July 2001 (art. 4 and 9) [13]. These regulations have been further extended through implementation of the "new" EU BSS defined in Directive 2013/59/Euratom [14].

2. Monitoring natural radioactivity in the Belgian national radiological surveillance program

Since its very beginning, the radiological surveillance program of FANC [15,16] included monitoring of the environmental impact of the phosphate industry on the quality of the Grote Laak and Winterbeek rivers. At the beginning of 2010 FANC set up a pilot study on the environmental impact of other sites and activities involving NORM [17]. The study concluded on the need of extending the part of the national radiological surveillance program dedicated to NORM, and from 2012 a number of additional sites and matrices have been monitored. This additional monitoring includes the following categories:

- Industries involving NORM which are still in operation: monitoring of discharge water, of groundwater and leachate around disposal sites, etc.
- Legacy sites: several former disposal sites for NORM (e.g. old phosphogypsum stacks) are scattered throughout the country [18]. Most of them had been identified during the aerial gamma spectrometry survey of Belgium carried out by the Geological Service of Belgium in the 1990s [11,12]. The list of these sites has been published in Belgian Official Gazette as anthropogenic radon-prone areas [6].

- A general monitoring of groundwater and sediments of Belgian watercourses is carried out in collaboration with the competent environmental agencies (see section 5).
- Finally, since the implementation of art. 70 of the 2013/59/Euratom directive (EU BSS) regarding the control of the natural radioactivity of building materials, also the follow-up of construction products has been integrated into the radiological surveillance program [19].

3. Monitoring the natural radioactivity of building materials

Art. 75 of Directive 2013/59/Euratom requires Member States to identify building materials of concern from a radiation protection point of view taking into account the indicative list of Annex XIII of the Directive. To this end, FANC analysed relevant literature data and existing surveys (such as [20]) and incorporated the analysis of 40 samples of building materials each year in its radiological monitoring program. These samples are either collected directly from the producers, such as cement factories, or collected by retailers of construction products. The gathering of samples by retailers is made in collaboration with the services of the Ministry of Economy in charge of controlling the prescriptions of the Construction Product Regulations (CPR). The samples include a range of common construction products such as bricks, cements and superficial materials like ceramic tiles or natural stones. They are analysed by gamma spectrometry in order to determine the value of the activity concentration index (ACI) used as a screening tool for the identification of building materials potentially of concern.

$$ACI = C_{Ra\text{-}226}/ 300 + C_{Th\text{-}232}/ 200 + C_{K\text{-}40}/ 3000$$

Fig. 1 shows an overview of the average activity concentration index for the main categories of construction products. All building materials have an average activity concentration index below the screening value of 1 – except for granite tiles. The latter products being superficial materials, the related exposure however stays below the reference level of 1 mSv/y.

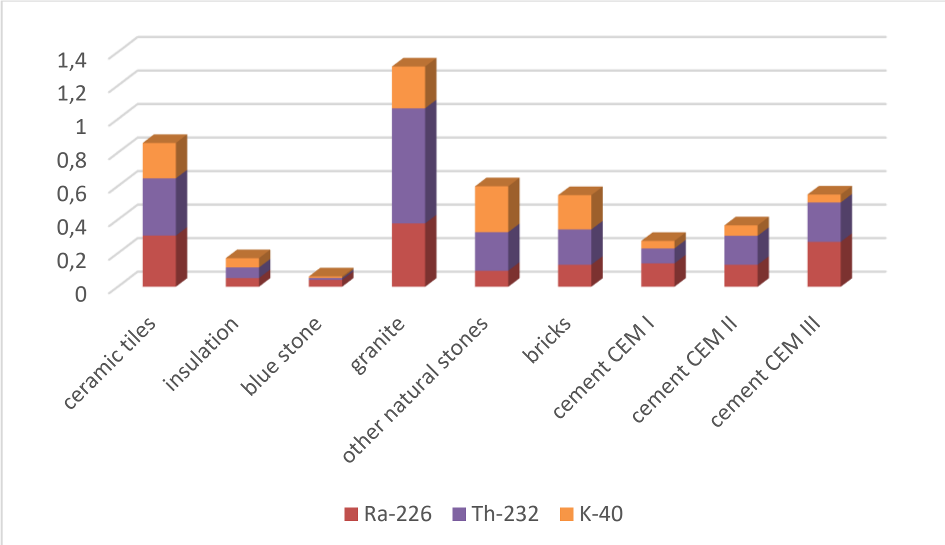


Fig. 1: average activity concentration index for categories of building material analysed in FANC's radiological surveillance programme

Knowing the activity concentration of the construction products, the external dose received by a person living in a standard room may easily be calculated using either the assessment method developed by the European Centre of Normalization (CEN) [21] or a specific calculation code such as RESRAD-BUILD [22]. On the basis of the results obtained in the context of the national monitoring programme, this external dose amounts to around 0.2 mSv/y.

4. Monitoring activities and sites involving NORM

4.1 Active sites

As mentioned in the introduction, several industrial activities deal with NORM, either because they process raw materials with an enhanced activity concentration in natural radionuclides or because their processes concentrate the natural radioactivity into some of the by-products or residues or in parts of the installations (scalings or deposits). Some of these industries involving NORM produce large amounts of residues. In Belgium, the bulk of these NORM residues has been produced by the phosphate industry. The type of residues depends on the process used to attack the phosphate ore [23]. The use of sulfuric acid to produce phosphoric acid from phosphate leads to the production of large amounts of phosphogypsum (calcium sulphate) according to the following reaction:

$$Ca_3(PO_4)_2 + 3H_2SO_4 \rightarrow 3CaSO_4 + 2H_3PO_4$$

The radium present in the phosphate ore follows the calcium and is essentially present in the phosphogypsum. Typical activity concentration of Ra-226 in phosphogypsum is around 0.5 – 1 Bq/g.

The use of hydrochloric acid to attack the phosphate ore produces another pattern of residues:

$$CaF_2.3[Ca_3(PO_4)_2] + 12\ HCl \rightarrow 3\ Ca(H_2PO_4)_2 + 6\ CaCl_2 + CaF_2$$

Here, radium-226 is present in the resulting calcium fluoride sludge and in the waste water - dissolved with the calcium chloride.

Activities involving NORM, including the disposal of NORM residues, must be registered by FANC according to articles 4 and 9 of the Royal Decree of July 20, 2001. There are currently 9 sites in Belgium which are registered for disposal of NORM: 4 of them are related to the phosphate industry, 1 to the disposal of filter-cakes from titanium dioxide production and another site is used for the disposal of residues from non-ferrous metal production. Next to these 6 “mono-landfills” where the waste of a single operator is disposed, there are also three landfills registered for the disposal of limited amounts of NORM.

The environmental monitoring of these active NORM disposal sites is generally performed by the operator – the type of monitoring (relevant parameters, frequency of monitoring) being imposed by FANC through the registration conditions.

4.2 Legacy sites

Industries involving NORM are often old industries that started their activities much before there was any regulation regarding NORM. Consequently, next to the still active disposal sites, around 20 legacy sites are spread around the country. A majority of them are related to the phosphate industry as well (mainly phosphogypsum stacks) or to its discharges (like the contamination of the Winterbeek and Grote Laak basin). In one case, the contaminated legacy is the consequence of the disposal of slags from ferro-niobium [24]. Next to these "NORM legacies", the production of radium and uranium in Olen and Brussels also led to contamination in the environment (see e.g. [7,25]). Monitoring of most of these legacies is carried out within the national surveillance program.

4.3 Some results

A summary of the monitoring results for the "NORM sites" is published in each yearly issue of FANC national radiological surveillance programme. Specifically for the sites of Tessenderlo Chemie, two of their disposal sites are still active. Although their phosphate production has stopped in 2013, these disposal sites are still in use for the disposal of remediation material (in particular from the remediation of the Winterbeek and Grote Laak rivers) and of residues from the decommissioning activities of their phosphate production unit.

The following matrices are monitored:

- For water: discharge and drainage water, leachate and groundwater; gross alpha and gross beta values are measured annually by the operator. All values are below the screening values for drinking water. The disposal of calcium fluoride sludge seems not to have any radiological impact on the groundwater – what can be explained by the clay-like character of calcium fluoride sludge.
- For air: radon in the outdoor air above and around the disposal site is monitored annually. Although the radon concentration at the surface of the site is increased by a factor 2 – 3, the radon concentration in the surroundings of the landfill is not enhanced. Heavy metals in the deposited dust around the disposal site are also periodically monitored by the operator – uranium was measured once, indicating a similar trend as the other heavy metals.

Another site of interest is the phosphogypsum stack located in Zelzate. Following the bankruptcy of the phosphate processing company in 2009, the stack had been taken over and remediated by a third company. Most of the stack is now covered by solar panels and some sections of the site are still in use for acceptance of gypsum – mainly from various remediation activities. Wet-stacking of phosphogypsum during the production time had led to the formation of acidic ponds on the stack. The management of this acidic water requested urgent measures from environmental authorities at the moment of the bankruptcy. Due to these acidic conditions, the (historic) leachate of the stack was also significantly contaminated. Before remediation, gross alpha activity in the historic leachate reached 8 Bq/litre – mainly due to the uranium contribution (up to 500 µg/litre). Gross alpha and gross beta activities both in leachate, effluent and groundwater of the stack have been monitored since. Remediation of the stack allowed a significant reduction of the gross alpha value in the historic leachate - down to 0.2 Bq/litre.

5. Collaborations with environmental agencies

In the context of NORM activities, natural radionuclides are a few elements among a set of other, non-radioactive, contaminants. All sites and activities involving NORM are already monitored by the regional environmental authorities. The application of an integrated approach where all contaminants – radioactive as well as non-radioactive – are tackled in a consistent manner is thus particularly relevant. Moreover, existence of monitoring networks and programmes for the non-radioactive contaminants allows synergies between FANC and competent environmental agencies.

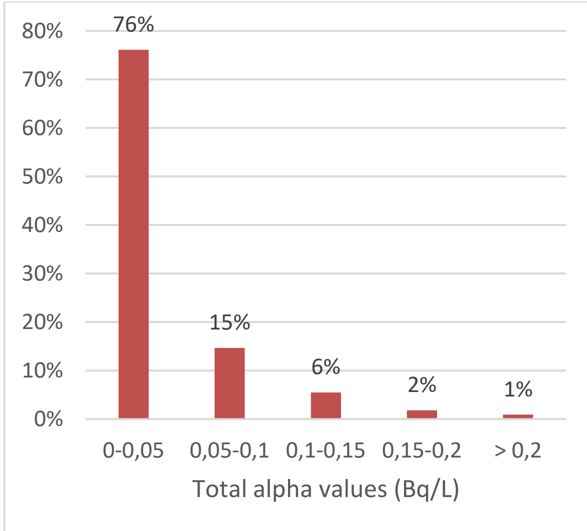
FANC has established collaboration with the following environmental agencies and institutes:

- In Flanders and Brussels: OVAM, VMM and Brussel Leefmilieu;
- In Wallonia: ISSeP and SPAQuE.

FANC may access the monitoring networks of these agencies: for instance, VMM in Flanders and ISSeP in Wallonia run a sediment surveillance network – each year a number of sediment samples from their surveillance network is analysed by FANC. This allows the determination of reference values for natural radioactivity in the sediments of Belgian watercourses. A similar process is carried out for measuring natural radioactivity in the groundwater bodies of the surveillance networks of ISSeP and Brussel Leefmilieu. Fig. 2 illustrates the distribution of gross alpha and radium-226 activity concentration in Walloon groundwater bodies [26].

In Wallonia, the natural radioactivity in water compartments of active landfills has also been systemically investigated in collaboration with ISSeP: leachate, discharge water and groundwater of landfills have been analysed. Some non-trivial values of natural radionuclides have been found in leachate of active landfills but no impact on groundwater has been observed.

In the framework of its collaboration with SPAQuE, FANC investigates groundwater and soil of several former industrial sites. These brownfields are selected on the basis of the history of their activities (i.e. did activity involving NORM take place on the site?) and on the basis of the degree of their environmental contamination. A number of sites related to steel and non-ferrous metal production activities have been selected for investigation, but also a dozen of old, now abandoned, landfills. Almost one third of these investigated old landfills displayed a non-trivial value of natural radioactivity in their groundwater – mainly due to the presence of uranium – with uranium concentration above 10 µg/litre (and in one case exceeding the World Health Organisation recommendations for uranium in drinking-water of 30 µg/litre). The presence of uranium in groundwater is associated to the presence of other non-radioactive contaminants such as chloride and cobalt [27].



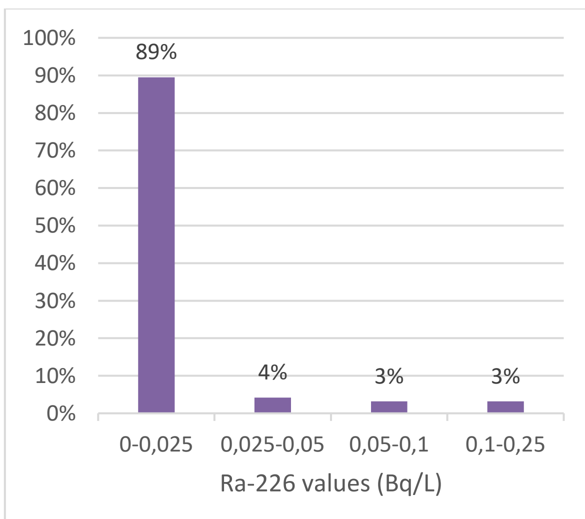


Fig. 2: Distribution of gross alpha values and ^{226}Ra activity in Walloon groundwater samples analysed since 2017 within FANC's radiological monitoring programme.

6. Conclusions

The "inventory" of natural radioactivity involves many components: radon indoor and outdoor, building material, disposal of NORM residues, environmental impact of discharges. Some industrial sectors in Belgium, such as the phosphate industry, deal with an enhanced activity concentration of natural radionuclides in their raw materials, residues or discharges. These industries are regulated through the Royal Decree of 20 July 2001 which obliges them to notify FANC. Based on these notifications and taking into account a graded-approach, FANC may impose on these activities appropriate dose-reduction and control measures, including, in relevant cases, a monitoring of their environmental impact. Currently, one counts in Belgium around 30 sites – either in operation or legacies – where NORM are disposed. The environmental monitoring of these sites is carried out directly by the operator and/or integrated in the national surveillance programme. According to monitoring results, the current impact of NORM sites and activities is of no direct concern from a radiation protection point of view.

Monitoring of natural radionuclides is closely connected to monitoring of other contaminants: in most cases, a radiological impact of NORM activities is associated with the presence of non-radioactive contaminants. The results of the monitoring of these non-radioactive contaminants may be used as a guide in order to set priorities and to optimise radiological monitoring resources.

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Environmental measurement techniques in case of incidents

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Abstract

The paper discusses the measurement techniques as developed in the context of the Belgian federal nuclear and radiological emergency plan. It explains how they are performed today by the mobile teams of the Civil Protection, the CBRN unit of Belgian Defense, IRE and SCK CEN, and complemented by aerial gamma spectrometry with helicopters and - more recently - drones.

The paper addresses also the experience feedback from incidents and drills, and highlights the growing importance given to the training of the involved actors.

Keywords: monitoring, measurement, EPR, aerial spectrometry, drones

Introduction

During a nuclear or radiological event with a real or potential release of radioactive material into the environment and/or public radiation exposure, monitoring the environment is essential to assess the impact and to decide on protective and remediation measures, if needed. Monitoring the environment for increased levels of radiation and/or radioactivity requires different measurement techniques complemented with calibrations and methods for the interpretation of the results. Environmental monitoring can be further complemented with monitoring the external and internal contamination of people, model calculations, … to complete the radiological picture.

The royal decree of March 2018 defines the general framework and actors involved in the nuclear and radiological emergency plan [1]. Experts and measurement teams from different institutes (FANC-AFCN, Civil Protection, Belgian Defence, FAVV-AFSCA , IRE, SCK CEN and the nuclear power plants) are involved, and a working group (GEPETO-CelMes) under the Presidency of the Federal Agency for Nuclear Control (FANC-AFCN) coordinates the preparedness of these measurement teams, defines the measurement strategy and all other measurement related activities, such as data exchange and communication.

Each year, four general GEPETO-CelMes meetings and a variable number of technical meetings as well as measurement drills are organized, to set up new measurement procedures and to optimize and train the existing procedures, including aspects such as personal protection, transfer of results, … The goal is to have measurement data available, during an event, for radiological advice by the evaluation cell (CELEVAL) at the Crisis Centre (NCCN, federal level). Hence the teams and laboratories executing the measurements are coordinated by a local coordinator in direct contact with the measurement cell at the federal level (CelMes-Fed), and are supported for logistics (set-up of a base-camp) and decontamination, if required by the civil protection services.

In the next parts, the different measurement techniques are discussed, starting with ground-based measurements by the mobile measurement teams, followed by aerial measurements split into Aerial Gamma Spectrometry, deploying large

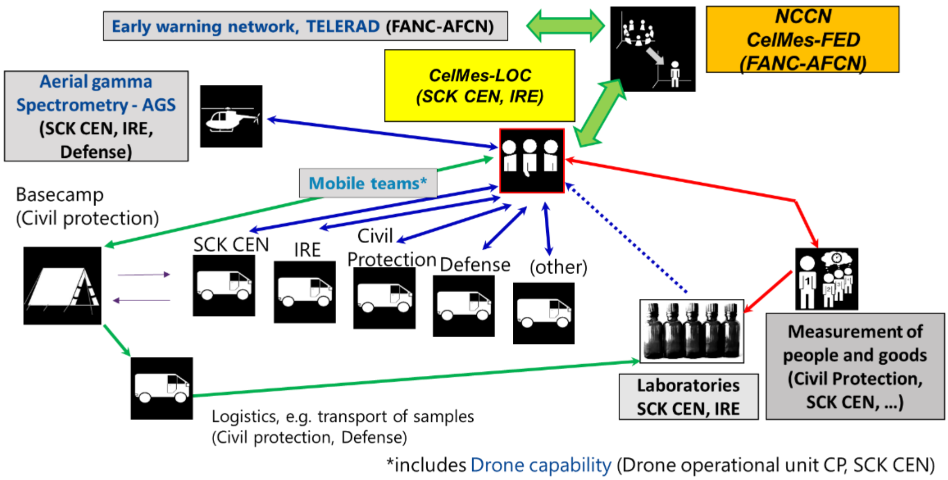

Figure 1. Schematic overview of the current organization of measurements in the context of the Belgian Nuclear and Radiological Emergency Plan, with a focus on the early phase. In later stages other institutes can be involved in different aspects, such as the food protection agency (FAVV-AFSCA) in large-scale food sampling. Mobile teams may include a drone measurement capability, but we will discuss this separately.

volume detectors loaded into helicopters, and Unmanned Aerial Vehicles (UAVs) or drones. Figure 1 shows schematically the organization of the radiological measurements in case of accidents. It must be noted that measurements are continuously performed by the early warning network TELERAD operated by the Federal Agency for Nuclear Control [2]. This information is available to the experts at the NCCN in real-time. This network serves as a first source of measurement data in case of an event.

Mobile measurement teams

The first goal of the mobile measurement teams is to extend the measurement data available from the TELERAD network, spatially (at specific locations of interest) and with regard to the type of information. TELERAD with its 254 stations across Belgium, gives mainly information on the ambient equivalent dose rate as a measure of the external radiation exposure. Some stations are equipped with spectroscopic detectors (NaI scintillators), giving also radionuclide specific information. A limited number of stations is equipped for air-sampling and real-time analyses. Twenty-three transportable ambient dose rate stations are available, to be set up in case of an event to create a denser network around the accident scene [2].

The mobile teams consist of trained personnel of the Civil Protection, the CBRN unit of Belgian Defence, IRE and SCK CEN. They all have dedicated vehicles equipped for performing direct environmental measurements and/or sampling. Although their organization is somewhat different (for example in number of people per team and types of measurements/sampling they perform …) they all use the same procedures to perform the measurements and/or sampling. In addition to these institutes, also the nuclear power plant operators have mobile teams, and the Food Agency (FAVV-AFSCA) will in a later phase collaborate in the collection of food samples.

Measuring the ambient equivalent dose and dose rate is the most common radiation measurement and gives direct information on enhanced levels of gamma or neutron radiation. Gamma and neutron detection instruments have in general a limited dose rate and energy range. Dose rates on the scene can vary from background level to values as high as 10 Sv/h. Background gamma dose rate levels from natural sources (soil, cosmic, …) in Belgium are in the range of around 60 nSv/h to 150 nSv/h. Because dose rate instruments for accurate measurement in the background range would be completely overloaded in high dose rate radiation fields, different detection methods are used (scintillators, Geiger-Muller counters, ionization chambers) sometimes integrated in one instrument. An important remark is that a dose rate measurement result alone gives no information on the radionuclides involved and can be the sum of different contributions: background, radioactive cloud passage, radiation from contaminated surfaces. To get a more complete picture of the radiological situation, information on both radionuclides and exposure pathways is necessary. This information can be (partly) available from the accident site (e.g. from stack monitoring), but the mobile measurement teams should be prepared to collect this information independently.

Handheld spectroscopic devices can be used in the field to identify the most common gamma-emitting radionuclides present. The teams have different medium-resolution scintillation-based detectors and identification software available, mainly based on NaI(Tl) and $LaBr_3$(Ce) crystals. When calibrated, they can be used for estimating the source strength (point source) or deposition levels (surface contamination). More accurate estimation of deposition levels can be done using high purity germanium (HPGe) detectors mounted on a tripod, (with the detector typically at 1 m facing the ground), and collecting spectra for half an hour up to one hour. The superior energy-resolution of these detectors allows to identify and quantify the activity concentration of all deposited radionuclides. This technique is in general referred to as in-situ gamma spectroscopy. Because of the long range of gamma rays in air, a large ground surface area contributes to the detector signal, allowing the detection of low contamination levels.

A fast and sensitive check of the gross contamination of the ground, but also of other surfaces such as for example vehicles, equipment, team members (check of external contamination) …, can be performed with contamination monitors. These are hand-held devices with a large two-dimensional probe (typical 100 to 300 cm^2). In general, these detectors consist of a scintillation layer of zinc sulfide doped with silver atoms. Because of the different range of alpha-particles compared to beta- and gamma-particles, and using a very thin first layer in combination with a somewhat thicker second layer, these instruments can discriminate between alpha and beta radiation, allowing to check also for non-gamma emitting radionuclides. The measured radiation quantity is in general displayed in count rate (e.g. in counts per second: cps). If the radionuclide is known and the detector is calibrated for different radionuclides the measured value can be easily converted into Bq/cm^2.

These direct measurements can be complemented with the analyses of samples. Samples of different type can be collected, ranging from air-samples to specific food samples (such as milk). Sampling of the air is extremely important to gain knowledge on the presence of (artificial) radioactivity in the air and to quantify the concentrations of different radionuclides. Radioactivity in the air will cause an internal contamination due to inhalation and can be a very important exposure pathway in an accidental release of radioactivity to the atmosphere. For sampling the air, the measurement teams use an air-sampler, typically set up on a tripod at 1 or 1,5 m above the ground, collecting particulates and/or iodine on a paper, respectively a charcoal filter, for a certain time and air-volume. The filters can be checked for increased radioactivity (outside the affected zone or in a shielded environment) by the mobile teams themselves, for example with a contamination monitor, or with specific equipment available in the intervention vehicles (gamma spectrometry, alpha-beta counting with discrimination of natural radioactivity). For a more accurate determination of concentration levels, the samples can be transported and analysed in the different laboratories, as discussed in [3].

Other samples include grass, soil, water and food samples (milk, vegetables, …). Instruction videos on sample collection (method, quantities required, …) have been made, allowing to train additional team members when required. These samples can be checked on radioactivity levels by the measurement teams and transported via a basecamp (which can be set up for logistic support) to the laboratories.

A special type of sample, a swipe sample, can be taken to collect radioactivity from surfaces. In this way a much larger surface, as compared with the use of contamination monitors, can be swiped and analysed on the scene via gamma spectrometry or by alpha-beta counting.

The mobile measurement teams can be directed to any location, based on the information required to complete the radiological picture in case of an event. However, pre-defined locations around all the Belgian nuclear installations are defined. These are selected to systematically cover the area around the installations in circles at different distances up to 20 km and with one point per 30° at every distance. All these locations are visited to check accessibility, background levels, etc.

Aerial gamma spectrometry

Aerial gamma spectrometry is a well-known technique to investigate the radioactive contamination of an extended area in the aftermath of an accident, in an efficient and fast way. In general large volume scintillation crystals (NaI), sometimes complemented with a HPGe detector, are deployed using a helicopter or small airplane flying tracks in a systematic way to survey the (potentially) affected area. Spectra are collected for one to a few seconds, stamped with information on the location and altitude above ground level (GPS, altimeter, …).

After correcting for altitude (attenuation of radiation in air), the ground contamination in Bq/m^2 can be derived for individual gamma emitting radionuclides (typically Cs-134, Cs-137, I-131) and/or - for example in case of complex spectra due to the presence of many radionuclides - the dose rate at ground level. For natural radioactivity, in general a homogeneous depth distribution can be assumed, and results are expressed in Bq/kg. Plotting this information directly gives information on the areas contaminated and the levels of contamination.

Two identical sets of large volume NaI(Tl) detectors (4x4 liter crystals), electronics and dedicated software have been ordered in 2007 by the Ministry of Interior Affairs in the context of the Belgian Federal Nuclear and Radiological Emergency plan. One set is available at IRE and another at SCK CEN.

Figure 2. AGS equipment mounted in an Agusta helicopter. The detectors are in the bottom cases, the electronics are in the top case.

In recent years the equipment has been made operational and tested in several helicopter measuring campaigns. Over 15 flights have been performed using private helicopters and Agusta (A109BA) helicopters from Belgian Defense (1st wing of Belgian Air Component operating from the Beauvechain airbase). In addition, one flight was performed with a small Cessna airplane from the Belgian federal police. The equipment is mounted inside the helicopter, height corrections are made based on GPS data combined with numerical elevation data. The typical output results from a measurement campaign are dose rate maps at ground level and contamination levels of specific radionuclides. Based on flights over historically contaminated terrains and from comparison with ground-based results and intercomparison between the two systems available, high confidence in the results has been obtained. The systems are ideal for mapping large-scale contamination and to search for sources. Typical flight parameters include a ground clearance of 100-150 m and a speed of 100 km/h, allowing to screen a 15 km x 15 km region with a relatively high spatial resolution (500 m line spacing) within 3 hours. All Belgian nuclear sites have been surveyed. Details of such surveys can for example be found in [4] and [5]. A map, as directly available after a flight, for the IRE site and its environment, is shown in Figure 3. The equipment can also be used car-borne, for example for screening urban environments, and is also regularly tested in this context.

Drones

The RPAS (Remotely Piloted Aircraft Systems) unit of the Civil Protection has the operational capacity to operate in emergency situations, with multirotor drones and trained pilots. SCK CEN on the other hand has started several years ago a research program on radiological monitoring with drones, developing specific detector-drone combinations and performing test flights in different radiological conditions. In the context of the CelMes activities, forces were combined: the drones owned and operated by Civil protection can be equipped with detectors developed and operated by SCK CEN team members.

The use of drones in nuclear and radiological emergency situations is of interest as an extension of ground (TELERAD, mobile teams) and AGS monitoring, to survey specific locations that may be difficult to access, including flying close to the accident scene. Over the last years several CelMes drone drills have been organized, testing the operational capabilities and acquiring experience with different detector-drone combinations, flight planning, interpretations of results, etc… These exercises include a contribution to the federal emergency exercise

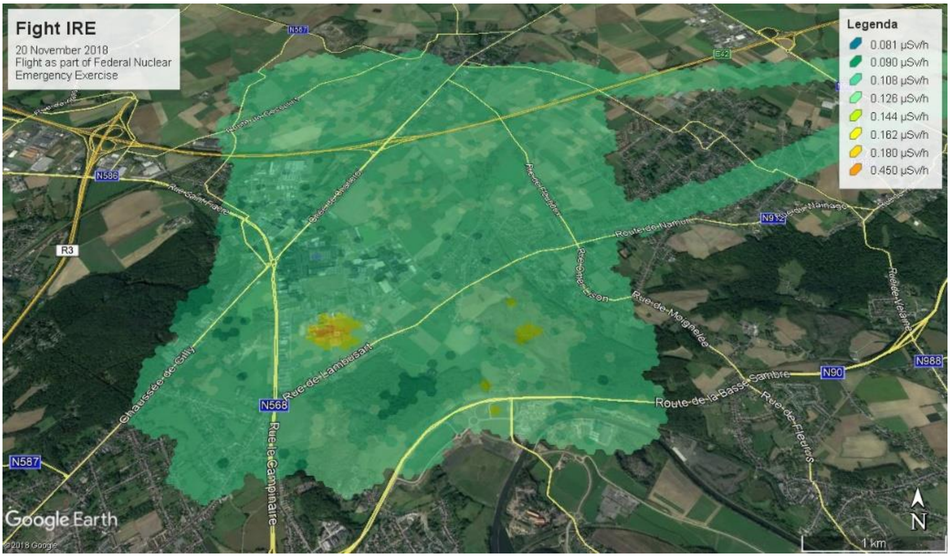

Figure 3. Aerial Gamma Spectrometry results as directly available after the helicopter flight for a survey performed in the context of a federal nuclear emergency exercise for the IRE facility. The hotspot corresponds to the location of the IRE facility (only a limited increased dose rate was observed, the color scales being chosen to make any increase visible).

in November 2018 for the IRE facility. A CsI detection and data handling system was attached to a VTOL (Vertical Take-Off and Landing) drone of the Belgian Civil Protection and flights were conducted in the close vicinity of the IRE chimney. The signatures of Mo-99 production during normal operation of the plant, i.e. the release of small, but detectable, amounts of noble gases (especially Xe-133 and Xe-135) could be detected and identified, and reconstructions clearly showed a plume transported from the chimney by the wind. This gave mainly qualitative information (presence and identification of artificial radionuclides). To quantify radioactive concentration levels in the air, more R&D is needed.

In March 2021, a CelMes drone drill was organized to map with different drone-detector combinations a historic contamination site. Different flights were executed over the Ra-226 contaminated D1 site in Olen and complemented with ground-based measurements. Details of this exercise can be found in [6]. A map of the site based on the count rate of the 609 keV gamma’s originating from Bi-

214 (daughter of Ra-226) from one-second spectra stamped with GPS coordinates is shown in Figure 4.

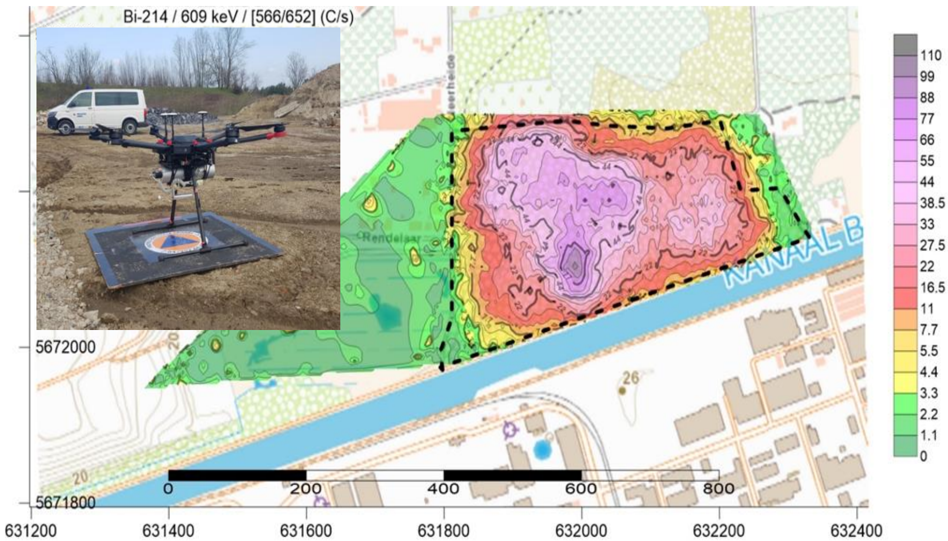

Figure 4. Map of contamination of the D1 site as measured by several drone flights at 25 m above ground level using a CsI spectroscopic detector (the count rate in the 609 keV gamma – originating from Bi-214 - region of the spectrum is shown. The insert shows one of the three drone-detector systems used during the drill (here equipped with a plastic scintillator for ambient equivalent dose rate measurements).

Finally, a drone exercise was organized during the Doel 2021 federal nuclear emergency exercise. The idea was to fly close to the stacks of Doel 1 and 2, but due to geo-fencing restrictions on the drone system it was not possible to fly very close to or inside the Doel site. However, deployment was tested and no increased levels could be detected nearby the site.

Experience from drills and exercises

Fortunately, nuclear incidents, especially with spread of radioactivity in the environment, are very rare. Specific measurements in the context of the federal nuclear emergency response for incidents on the Belgian territory have only been initiated two times: once in 2008 after a release of 45 GBq I-131 from the IRE facility. During this incident, with atmospheric release and deposition levels not giving rise to increased dose rate values, mainly samples (air, grass and food) have been collected with subsequent analyses in the laboratories. The importance of robust and trained sampling procedures was identified as a “lesson learned”. A second time, in 2017, in the aftermath of an incident (classified as an anomaly, during a controlled steam release, without radiological consequences), one mobile team was sent on location to confirm that no radioactive releases took place. Different direct measurements and sampling (including swipes) with subsequent analyses in the laboratory were performed.

Experience is consequently mainly gained from trainings, drills and full-scale exercises. Trainings are organized on a regular basis in the different participating institutes. Drills are set up in a CelMes context, allowing to test measurement procedures (and all aspect related to it), to learn from each other and to collaborate in an effective way. Several drills have been organized in the past decade (typically 1-2/year) with specific objectives. Scenarios making the drills as realistic as possible have been making use of the following options: (1) radiation sources are used, (2) historic contaminated sites are visited, (3) measurements are performed in the vicinity of installations releasing limited amounts of radioactivity during normal operation and (4) short-lived artificial radionuclides (such as Tc-99m) are used to contaminate areas in a controlled way. Also, inter-comparisons are organized during such drills, allowing to compare results from both direct measurements and sampling by different teams, using different instruments for the direct measurements. Finally, to test and train the integration of the measurement capacity, and the exchange of data and information in full scale emergencies, the measurement cell (CelMes) also participates at least once a year in a federal nuclear and radiological emergency exercise.

Apart from the continuous work on the preparedness to perform in case of an event the different measurements discussed, and the efforts required to introduce new technologies (e.g. drone-born measurements), three additional elements are identified. First, the efficient transfer, processing and visualization of data. Track-and-trace apps, electronic measurement forms, the set-up of a data warehouse and GIS visualization capabilities are explored, tested and implemented. Second, to guarantee confidence in the measurements of different teams and to make validation of results possible, in case of a large-scale real event, it is important to define a reference area, allowing to intercompare results from different teams and techniques, including foreign teams. Third, measurements should serve impact assessments and decisions. To support this effectively, a measurement strategy is required. Such a strategy, operationally implementable, is mainly built based on experience, including the development and use of tools, for a full range of imaginable event-scenarios.

Conclusions

A range of measurement techniques is required to get a full picture of the radiological situation in case of a nuclear or radiological event. Many techniques are available, complementing each other, with some focusing on covering large areas while others giving detailed information on, for example, the activity levels in specific food products. Especially during the last decade, a lot of effort went into setting-up training techniques and procedures, including aerial measurements, and into following evolutions in detection and ICT capabilities.

Acknowledgments

Being prepared for environmental measurements in the case of a nuclear or radiological event is a work of many people from different organizations and collaborating towards a common goal. The realizations described here are consequently the work of many: work ranging from building expertise, discussing, testing and exercising both in their home institutes as in the framework of Gepeto-CelMes and the federal emergency plan. Part of this work is funded under the Convention Interior Affairs.

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How the European Commission verifies the facilities for radioactivity monitoring and supports laboratories and the harmonisation of measurements

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Abstract

This article describes how the European Commission oversees and supports the many laboratories in charge of radioactivity monitoring in the Member States. The work is stipulated in the Euratom treaty; it serves to protect the general public against the dangers of ionizing radiation. In addition to conducting verification visits, the Commission provides metrological support like certified reference materials, proficiency tests and training. The radioactive reference materials are produced at the JRC-Geel facility in Belgium, which is briefly described.

Keywords: monitoring, measurement, harmonisation, interlaboratory comparison, reference materials, EURATOM

1. Introduction

The European Commission's Joint Research Centre was created through explicit mention in Article 8 of the Euratom Treaty [1] that came into force in 1958. A research site was created in Geel, Belgium and it is now called JRC-Geel. In the period 1960-1992 it was called Central Bureau for Nuclear Measurements and was assigned the specific task of establishing a common system of nuclear measurements. This task was realised by, amongst other actions, supporting the international radionuclide metrology community and contributing to BIPM[2] key comparisons of radioactivity. These key comparisons form the basis for realisation of the unit Bq and international equivalence. Over the years, the task of harmonising radioactivity measurements has grown. The reasons are many.

- There are many radionuclides: about 3500, albeit "only" a few hundred are important to monitoring for the protection of the citizens. But all radionuclides have implications in nuclear physics and fundamental science and are therefore important to study. All decay schemes are different (although there are of course similarities) so it is not evident that showing proficiency in measuring one radionuclide helps in measuring another radionuclide.
- The number of nuclear installations in the world has increased and is expected to increase (also installations under decommissioning require monitoring). Radioactivity doesn't stop at borders. Therefore, adequate monitoring activities for normal and emergency situations must be in place and tested regularly.
- The risk of malicious use of nuclear and radioactive material is ever-present and also require preparedness from monitoring laboratories.
- The number of matrices that need to be monitored is huge. It is a technological challenge to use proper techniques to measure such diverging matrices like water, soil, mixed diet, industrial products etc.

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[2] BIPM = Bureau International de Poid et Mesures. International organisation established by the metre convention and in charge of the SI system of units. Located in Sèvres, outside Paris

- Nuclear medicine is developing fast and an increasing number of radionuclides are used, or proposed to be used, in innovative medical applications.
- Radionuclides that are present in very low concentrations have become indispensable tools to study processes in nature and industry, so-called tracer studies. This can help understanding such diverging issues like ocean currents, uptake in the food chain and enable dating of hydrothermal plumes or archaeological artefacts.

The Radiation Protection and Nuclear Safety Unit (ENER D3) of the European Commission's Directorate-general for energy (DG ENER) is in charge of implementing Chapter 3 (Article 30-39) of the Euratom treaty. Under Article 35 all Member States must establish the facilities necessary to carry out continuous monitoring of the levels of radioactivity in air, water and soil, and to ensure compliance with basic safety standards [2]. This includes monitoring of liquid and gaseous radioactive discharges from nuclear facilities. Article 35 also gives the European Commission the right of access to such facilities to verify their operation and efficiency [3].

2. JRC-Laboratories

The laboratories at JRC-Geel are now specifically set up to produce reference materials and perform reference measurements. Consequently, between 1992 and 2016 the name of the JRC-Geel site was Institute for Reference Materials and Measurements (IRMM), a label that still appears on many reference materials that are available in its catalogue[3].

2.1. The radionuclide metrology team - RN

The Radionuclide metrology team (RN) of JRC-Geel began operation already in 1959 with offices at the Belgian nuclear research centre SCK CEN in Mol (a year before the JRC-Geel site was constructed). Over the years it has developed and built radiation detectors tailored for certain types of radionuclides in order to perform so-called primary standardisation, i.e. to be able to measure

[3] https://ec.europa.eu/jrc/en/science-update/welcome-irmm-reference-materials-catalogue

radioactivity without having to first measure a calibration source. The laboratory is also equipped with state-of-the-art commercially available instrumentation, including HPGe-detectors, liquid scintillation counters and an alpha-particle spectrometer. In addition, it is operating a laboratory in the 225 m deep underground research facility HADES [4]. The gamma-ray detectors in HADES have several orders of magnitude lower background compared to above-ground, due to the reduction of cosmogenic radiation. The underground detectors are highly useful for robust characterisation of reference materials both for JRC and for other stakeholders like IAEA and NMIs (National metrology Institutes).

Figure 1. Interior view of the HADES underground research facility showing the area with JRC's HPGe detectors (under blue dust-covers) operated by the RN team of JRC-Geel. Source: JRC with permission from Euridice.

2.2. Reference Materials Production Facility

The non-nuclear reference material activities at JRC-Geel started in the mid 1980's, whereby a first processing hall for material processing was built up. It should be noted that the European Commission had already set up the Bureau Communautaire de Reference (BCR) in 1973, under which non-nuclear reference materials were produced in a network of European laboratories, mainly from academia. When the BCR-activities ceased, all the reference materials that had been developed during the BCR- programme were moved to JRC-Geel in 1994. From that point onward, JRC-Geel (IRMM until 2016) became responsible for stock keeping and replacement of CRMs (Certified Reference Materials) that were sold out, and for the development of new CRMs. Between 1994 and 2010 many important developments took place at JRC-Geel with respect to Reference Material Production. One main development was JRC-Geel's fundamental contributions to the ISO Guide 30 series. ISO Guide 34 later became ISO 17034:2017, which is the international standard for the production of reference materials. In addition, in 2004 JRC-Geel became the first European Reference Material producer to get an ISO accreditation for reference material production. In 2008 the construction of a new reference material processing building was started, as the processing facility from the mid 1980's had become outdated. Since the beginning of 2011, JRC-Geel is operating one of the most modern and versatile reference processing facilities in the world. It is centered around a main processing hall split in four quadrants with individual air-handling and flexible wall arrangements. The facility encompasses processing equipment for stabilisation and homogenisation of a wide variety of matrices with the purpose of improving homogeneity and stability of target parameters to be certified in those matrices, e.g. freeze-dryers, autoclave, large cutter/mixer, cryogenic milling and three-dimensional mixers. Other equipment is also available in the hands of an experienced and innovative team of scientists and technicians.

In the period 2011-2021, the reference materials unit produced about 20 different certified reference materials (CRMs) per year and about 30,000 units yearly. Most of these were not radioactive materials but for example, for testing cadmium in chocolate, GMO in maize, PCB in feed etc. These diverse applications put high demands on the instrumentation in the laboratory.

In the same period (2011-2021) there were about 6000 units of 30 different radioactive reference materials produced.

Figure 2. Wide angle photo of part of the interior of the JRC-Geel's reference materials processing facility. Source: JRC.

Figure 3. Example of agricultural products before commencing reference material processing. Left: maize from the local market. Right: hay from Chernobyl. Source: JRC

As an example, the steps involved in producing a hay reference material used for testing a new CEN standard (EN17462) are given below. After drying and cutting, the material was milled, sieved and homogenised before spiking with radioactive solutions. After that it was again homogenised and then bottled. This particular material contained ^{137}Cs taken up "naturally" in the field, but ^{131}I and ^{134}Cs needed to be added by spiking. This was done by producing a slurry containing hay and acetone in a rotary evaporator flask. The radioactive solutions

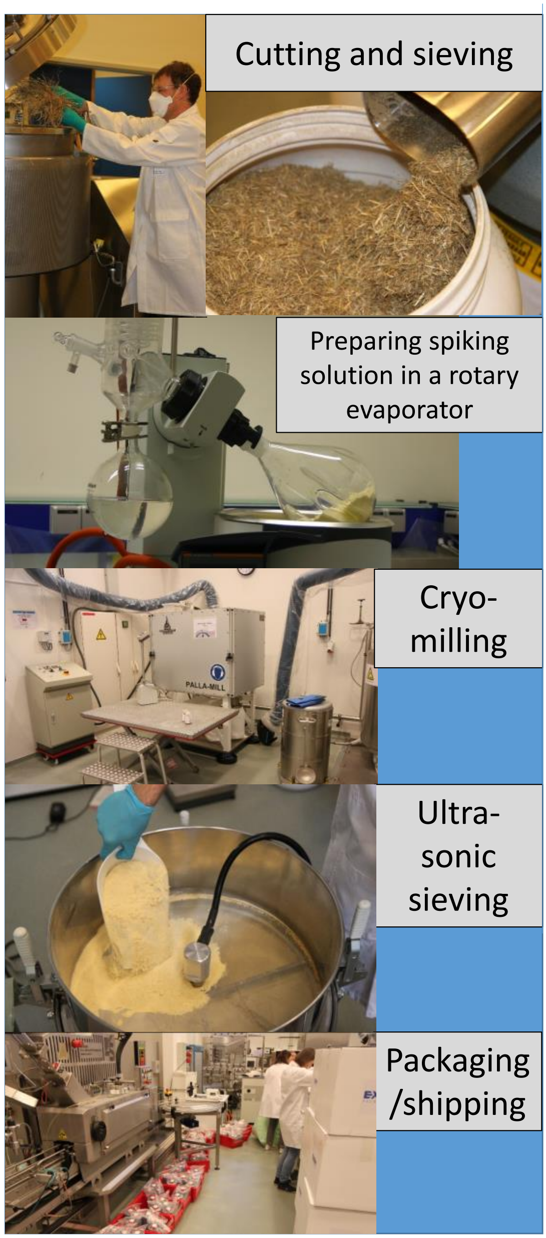

Figure 4. A few selected steps involved in reference material processing. Top: Hey from Chernobyl. Middle three photos: maize. Bottom: drinking water. Source: JRC.

were added to this slurry and mixed. Then, the acetone was evaporated and the spiked powder was mixed with the required amount of non-spiked hay powder.

3. Overview of Interlaboratory Comparisons 2011-2021

3.1. European Proficiency Tests in support of Article 35

Article 35 of the Euratom treaty stipulates that the Member States (MS) must monitor radioactivity in the environment (air, water, soil) and that the Commission has the right to verify the operation of the monitoring facilities. Each year, Directorate-General for Energy (DG ENER) conducts around 4-6 verification visits to the Member States.

Article 39 stipulates that the JRC shall assist the Commission in the work in Chapter 3 (Article 30-39). One such support is to perform proficieny tests (PTs) of radioactivity measurements. This work, which the JRC begun in 2003 [5], is nicely complementary to the work of DG ENER. Each EU Member State can be checked each year (depending on the frequency by which the PTs are carried out) albeit for a specific radionuclide vector and matrix. Such PTs enable

- Laboratories to show proficiency and (if succesful) use this to apply for accreditation
- Laboratories and regulatory authorities to discover flaws and gaps in radioactivity measurement processes and to improve the quality of measurements.
- The international measurement community to identify best practices and give input to standardisation processes.

3.2. Interlaboratory Comparisons

Interlaboratory comparisons (ILCs) are carried out in different ways and for different reasons. It is common that the reference values for reference materials are established by asking a number of expert laboratories to measure the activity. Furthermore, to test procedures prescribed in draft documentary standards, so called collaborative trials are performed. These are interlaboratory comparisons in which the participants (an adequate mixture of non-experienced and expert

Figure 5. Bottles with radon in water ready to be shipped to monitoring laboratories. Source:JRC.

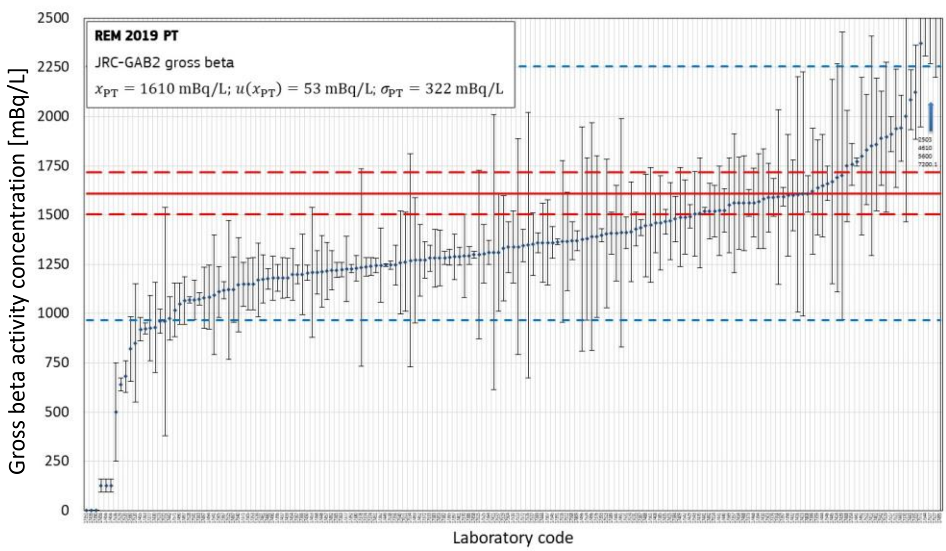

Figure 6. Example of results from a European Proficiency Test. In this case the gross beta activity in drinking water reported by 154 laboratories. The data is sorted from the lowest reported value to the highest. The solid red line is the reference value and the dashed red lines show the 2σ uncertainties of the reference value. The dashed blue lines show the $2\sigma_{PT}$ by which the laboratories' values are compared [6].

Table 1. List of the European Proficiency Tests (PTs)[3] that JRC-Geel organised in the period 2011-2021. Source: JRC.

Year	Topic	Reference Materials (RM)	Number of produced RM units	Radionuclide(s)	Number of participants	Comment
2011	Bilberries	Bilberries from Chernobyl (catalogue number "IRMM-426")	1200	^{90}Sr, ^{40}K, ^{137}Cs	88	The PT RM was made into a CRM
2012	Drinking water	Two commercial mineral waters and two spiked blank waters	1883	Gross-alpha activity and gross-beta activity	71	
2014	Air filters	Each participant provided its own filter which was spiked by JRC	80	^{137}Cs	78	
2016	Air filters	Each participant provided its own filter which was spiked by JRC	70	^{131}I, ^{134}Cs, ^{137}Cs	67	
2017	Maize	Maize from the local market that was spiked	160	^{131}I, ^{134}Cs, ^{137}Cs	120	
2018	Drinking water	Natural spring water from a source in Austria	160	^{222}Rn	101	
2019	Drinking water	Two commercial mineral waters and two spiked blank waters	920	Gross-alpha activity and gross-beta activity	154	
2020	Building materials	Cement Blocks of expanded clay Pulverized expanded clay Blocks	1110	^{40}K, ^{226}Ra, ^{228}Ra , ^{228}Th	102	Delayed execution due to Covid situation

[3] The European Proficiency Tests have be organised with different names. Lately they were called REM 2019 PT (with the digits giving the year it was announced and REM standing for Radioactivity Environmental Monitoring). In the past they were also called ICS (International Comparison Scheme).

Table 2. List of the ILCs (InterLaboratory Comparisons that JRC-Geel organised in the period 2011-2021. Source: JRC.

Year	Context	Reference Materials (RM)	Number of produced RM units	Radionuclide(s)	Number of participants	Comment	Topic
2013	EURAMET/EMRP-project: MetroMetal	Steel disks from Simpelkamp, germany	Provided by PTB, germany	^{60}Co	13		Simpelkamp steel
2013	EURAMET/EMRP-project: MetroMetal	Steel disks from Vuhz, Czechia	Provided by CMI, Czechia	^{60}Co	13		Vuhz steel
2014	EURAMET/EMRP-project: MetroMetal	Slag	Provided by CIEMAT, Spain	^{226}Ra	10		Slag
2014	EURAMET/EMRP-project: MetroMetal	Fume dust	Provided by PTB, Germany	^{137}Cs, ^{60}Co	12		fume dust
2018	CEN collaborative trial to test standard EN17462	Poultry feed (2 different types) Maize (2 different types) Hay	400	^{131}I, ^{134}Cs, ^{137}Cs	13		maize
2018	Rn-in-water Pilot-PT	Natural spring water from one source in Austria and one in Germany	115	^{222}Rn	14		Drinking water
2021	CEN collaborative trial on methods for measuring building materials, standard EN 17216	Phosphogypsum plaster Cement Concrete as cubes and powder Pulverized aggregates Pulverized expanded clay blocks	1000	^{40}K, ^{226}Ra, ^{228}Ra, ^{228}Th	not yet known	Production and certification ongoing (delayed due to Covid situation)	Building materials

labs) must follow the draft standard. When only very few units of a reference materials are available and considered stable enough to be sent around many times, one can choose to perform a so-called round-robin ILC. In such case the reference material is measured by one participant and then shipped to the next and so on. Table 2 shows a list of ILCs that JRC-Geel organised out 2011-2021.

4. Conclusions and challenges

The Chernobyl accident highlighted the fact that environmental radioactivity monitoring in Europe should be improved. The situation has indeed much improved since then, due to many factors: (i) the instrumentation evolved and improved, (ii) there are more international standards and reference materials available and (iii) efforts have been directed towards legislation and verification, prompted by the continuous public and political controversy on the use of nuclear power. This improved situation does not mean that authorities can relax or become complacent. It is important to try to anticipate possible future scenarios and perform emergency exercises.

There is also concern about a lack of radiochemists in Europe. It was concluded from many workshops that the level of knowledge amongst the staff is the most important prerequisite to make good radioactivity measurements, since radioactivity in the environment is complex, covering hundreds of radionuclides and a multitude of matrices. It is not possible to make routine methods for all situations, but well-educated and experienced staff can find good solutions also in new and complex scenarios.

For certain materials it is clear that the sampling is very difficult. For example when sampling water for radon measurements [7], there are many occasions for radon being lost, as it is an inert gas that easily can escape when transferring water to measurement beakers or during transport. When sampling soil or crops in a field, the exact location is critical and it is important to strictly apply a well-defined procedure and to monitor all environmental parameters at the time of sampling.

The Article 35 experts and Member State laboratories often request exercises to test the sampling. The first PT that JRC organised that encompasses elements of sampling is the most recent REM PT on building materials in which the participants are requested to measure a complete expanded-clay block. They will need to crush and possibly mill and homogenise the material before measurement. The JRC has plans for performing sampling exercises on radon in water, and discussing possibilities for growing radioactive crop in green-houses, where participants should be able to come and perform sampling in a more controlled way than in an open field. The key factor for developing JRC's REM PT scheme to respond to the requests from Member State laboratories is linked to human resources, as the JRC infrastructure is excellently suited for producing and characterising radioactive reference materials. The infrastructure also allows to perform more frequent PTs.

In the period 2011-2021, the JRC-Geel produced around 6000 units of radioactive reference materials of 30 different types. These materials have contributed to improve radioactivity measurements all over Europe, thereby contributing to better protection of the citizens against the dangers of ionising radiation. The authors are grateful for input from stakeholders regarding radioactive reference materials and ILCs that solve specific or general problems and encourage further feedback on such topics.

Acknowledgements

The authors would like to thank all European monitoring laboratories for the very good collaboration over the past 20 years. They would also like to thank laboratories that contribute the certification of JRC radioactive reference material, in particular, IAEA-Seibersdorf, IAEA- Monaco, SCK CEN in Mol, and CEA-LNHB in Paris. Many thanks for good collaboration to Austrian Agency for Health and Food Safety (AGES)-Linz and Prof. Henning von Philipsborn (Universität Regensburg).

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Involvement of stakeholders - Experiences from Ireland

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Abstract

Ireland is a non-nuclear country, but the consequences of a nuclear accident abroad has been identified as a key risk, mainly due to its economic impact on agriculture and tourism. For that reason, the risk of potential nuclear accidents is integrated in the Irish emergency management system, following an all-hazards approach.

In order to be better prepared for emergencies and understand the public behaviour, stakeholders are engaged through a national food and feed panel. The panel has discussed key issues regarding the placement of Irish foodstuffs in the marketplace following contamination from a nuclear accident abroad.

In addition, public concerns about radiation risks are assessed by surveys conducted periodically by the Environmental Protection Agency.

Keywords: stakeholder involvement, EPR, food and feed contamination, public survey

Introduction

A severe accident at a nuclear power plant in western Europe could give rise to widespread low-level radioactive contamination in Ireland. In the event of such an accident, the most significant route of potential radiation exposure for people in Ireland would be the consumption of contaminated food. However, most of this ingestion dose could be averted through the introduction of protective actions to prevent food becoming contaminated or the implementation of food controls to stop the sale of contaminated food.

The greatest impact on Ireland from a nuclear accident in western Europe would be on Ireland's economy and not on public health. A nuclear accident in Europe could have significant non-radiological impacts in Ireland though the loss of trade and tourism. In 2016 Ireland's Economic and Social Research Institute published a report on the estimated costs to Ireland's economy, from the impacts on agriculture, tourism and business through lost days and the cost of monitoring resulting from a nuclear accident in western Europe [1]. Losses to the economy were estimated to range from approximately €4bn for a scenario where there was no contamination in Ireland up to approximately €161bn for the worst-case scenario. Since agriculture and food are very important for Ireland's economy, engagement with stakeholders in the food and agriculture industry in the preparedness phase is crucial.

Emergency Management in Ireland

As a small non-nuclear country, Ireland maintains close links with international stakeholders through active participation in Emergency Preparedness and Response (EPR) committees and working groups such as those in the International Atomic Energy Agency (IAEA), Nuclear Energy Agency (NEA) and other bodies.

At a national level, an all-of-Government and all-hazards approach is adopted for EPR. The Government Taskforce on Emergency Planning, which includes all Government Departments and some state agencies, meets approximately every 2 months to assess new and emerging risks. The representatives on the Government Taskforce on Emergency Planning also participate in the National Emergency Coordination Group when it is convened in response to an emergency. The fact that the same representatives are involved in both groups means that relationships are established between stakeholders during the preparedness phase and this is very beneficial for emergency response.

In line with EU reporting requirements, the Government Task Force on Emergency Planning carries out a national risk assessment every 3 years. The 2020 national risk assessment identified 16 key risks for Ireland, one of which is a nuclear accident abroad [2]. This risk assessment considered the reasonable worst-case scenario which is a severe nuclear accident in the UK or western Europe. This type of emergency was assessed to be of low likelihood (51 to 100 years between occurrences) but if it occurred, it could have a very high impact including widespread effects of extended duration. In preparing this risk assessment, stakeholders were involved in expert focus groups to assess each of the risks. A household emergency preparedness survey was carried out so that the public could rate each risk. This public participation will be used to assist with awareness-raising, public information and education.

Ireland's all hazards approach to emergency management is important for ensuring Ireland's preparedness for low probability events such as nuclear accidents. In Ireland a systems approach is used for emergency management at national, regional and local levels (see Figure 1).

Figure 1. Systems approach to emergency management

Stakeholder Engagement with the Food and Feed Industry

A national food and feed stakeholder panel was established in Ireland in 2014 to discuss issues to do with the placement of Irish foodstuffs (meat, dairy and crops) in the marketplace (within and outside Ireland) following contamination from a nuclear accident abroad. Most participants in this stakeholder panel have no background in radiation but all of them are either involved in emergency preparedness and response or are involved in the food industry in Ireland and have insight into food contamination issues.

One of the key issues that was identified by this panel was communications. Following a nuclear accident, it is critical that communication paths are clear to avoid confusion and to ensure the public and industry are not receiving mixed messages. It was recognised that key stakeholders in the food industry must be notified directly and quickly in the event of a nuclear emergency so that they do not receive their information from the media. Communications between industries is also very important e.g. between suppliers and processors. Therefore, all stakeholders in the food industry must be involved in emergency communication plans. It was recommended that careful consideration is given when selecting who will deliver communications to the public as the public are more likely to trust independent health and scientific experts rather than politicians or those with vested interests in the food industry.

To respond effectively to a nuclear or radiological emergency there must be an understanding of the public perception of risk. Therefore, stakeholder engagement in the preparedness phase is important to understand consumer behaviour. In an emergency, as happened at the start of the COVID pandemic, there could be an over-reaction or irrational response from the public such as panic buying. Consumers cannot be treated as a single entity as some groups have special sensitivity. Since no two accidents are the same, emergency response structures must be flexible, proportionate and scalable.

Radioactive contamination from a nuclear accident can persist for many years. Measurement of radioactivity in food samples is key for public reassurance and customer confidence. Therefore, there must be laboratory capacity to facilitate this. The expansion of laboratory operations to accommodate increased testing demands could be challenging, particularly given the constraints associated with accreditation. While accredited laboratories are required for official certification, other laboratories or industry could introduce screening services.

An accident in Europe will affect trade in most European Union (EU) Member States and therefore countries need to align their messages and the EU response will be critical including the introduction of Regulations on maximum permitted levels in food and feedstuffs. Other food contamination incidents have shown that the opening of international markets could take approximately 15 years.

Public Surveys

The Environmental Protection Agency (EPA) in Ireland carries out surveys to assess the public's attitudes to radiation. The most recent survey was carried out online in October 2020 [3]. The objectives of this survey were to assess the levels of awareness of radiation in Ireland and find out what, if any, aspects of radiation people were concerned about. A total of 1,149 people over the age of 18 took part in the survey. Quotas were set on gender, age, social class and region and the data was weighted to achieve a sample aligned with the national adult population.

In this survey 28% of the respondents were either very concerned or fairly concerned about radiation while 67% were not very concerned or not concerned at all. Figure 2 shows that there has been a steady decline in concern about radiation when compared to previous surveys. The reasons for this reduction in concern about radiation are not known. It could be that people have better access to information which addresses their concerns, or it could be that there are less media articles about nuclear power and radiation. The aspects of radiation that were of most concern to the 28% (322 respondents) who were very or fairly concerned about radiation were nuclear plants abroad, damage to the environment and radon gas.

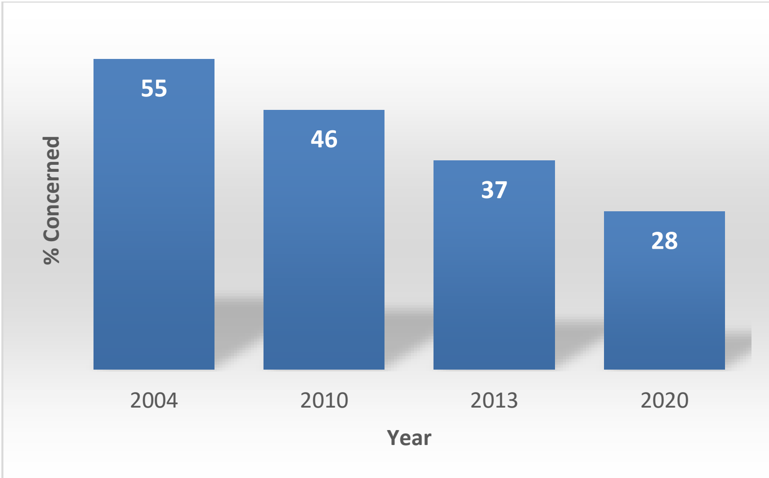

Figure 2. Percentage of survey participants concerned about radiation

In this survey, as in previous surveys, the awareness of radon was high at 82%. The lowest awareness was in the under 35-age category, which would suggest that this group should be targeted in radon awareness campaigns, particularly as people in this age group may be buying their first home. Of the 82% (938 respondents) who were aware of radon, only 25% were very concerned or fairly concerned about it, with 73% not very concerned or not concerned at all. In addition, 66% of those who were aware of radon were not very likely or not at all likely to have their homes tested for radon. The reasons for this included:

- Believe home is unaffected (19%)
- Don't know enough about radon (14%)
- Low risk area (14%)
- New home or radon barrier (14%)
- Not a priority now (11%)
- Unaware of how to do it (8%)

Only 3% said it was because a radon test was too expensive and 2% said it was because radon remediation was too expensive, which suggests that cost is not the main barrier to radon testing. Thirty-five per cent of participants did not believe that the risk from radon in Ireland was greater than the risk of a nuclear accident somewhere near the country, 23% believed the risk from radon was greater and 41% did not know. This indicates that more needs to be done to address this lack of understanding.

In the event of a nuclear accident in a country close to Ireland, 88% indicated that they would follow advice from the government and/or scientific organisations. If information on radiation was needed the most likely organisation that the public would turn to would be the Department of Environment followed by the EPA. The outcomes from this survey will be used by the EPA to raise awareness and counteract misinformation. Infographics or short videos that can be used on the EPA website, social media and in presentations may be developed.

Conclusion

Experience from the Chernobyl and Fukushima nuclear power plant accidents has shown that stigmatisation of food and other products, by both consumers and retailers who anticipate the fears of consumers, can be considerable. Public reassurance can be enhanced by the timely introduction of protective actions in an emergency. Communications with the public and key stakeholders in an emergency is of key importance and this is guided in Ireland through public surveys and the outcomes from the food and feed stakeholder panel.

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