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# THIRD EUROPEAN CONGRESS

## Belgische Bijdrage
## Participation belge

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ANNALES
DE
L'ASSOCIATION BELGE
DE
RADIOPROTECTION

Le troisième congrès régional de European IRPA (International Radiation Protection Association) a eu lieu à Helsinki Buenos Aires du 14 au 18 juin 2010
Ce numéro 3 du Volume 35 des Annales de l'Association belge de Radioprotection reprend des articles d'auteurs ou co-auteurs belges.

Van 14 tot 18 juni 2010 vond te Helsinki het derde regionaal congres van de European IRPA (International Radiation Protection Association).
Dit nummer, nr 3 van Volume 35 van de Annalen van de Belgische Vereniging voor Stralingsbescherming, herneemt de artikels met Belgische auteurs of medeauteurs.

# THIRD EUROPEAN IRPA REGIONAL CONGRESS

## Belgische Bijdragen
## Participation belge

**SOMMAIRE** **INHOUD**

## SOMMAIRE INHOUD

# Public Health Perspective in Radiological Protection

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## Abstract
Recent new insights about radon risk and increasing patient exposure due to medical imaging, as well as unexpected cardiovascular effects of ionizing radiation are challenging our classical radiological protection approaches and should be viewed in a larger public health perspective. Concepts as global indoor air quality, long term sustainability, risk awareness or precaution ask for a wider approach encompassing scientific vigilance, value judgements, risk communication and sociological participation in risk governance. Progress in radiological protection needs a new transdisciplinary framing of complexity where social sciences and humanities are more actively involved to complete scientific insight.



## Text
Recent new insights about radon risk and the increasing patient exposure due to digitalisation of medical imaging are challenging our classical radiological protection approaches. Unexpected cardiovascular effects of ionizing radiation (at least for relatively low cumulative doses) and some other present science foci are challenging our expert culture and are questioning why the radiological protection community clarifies and embarks such health topics so late. In these important areas for *public health*, the current dose limitation system has been till recently almost not operational while justification and optimisation were not given the priority they deserve.
These – and other- health concerns regarding ionizing radiation occur in a *changing societal context* where scientific paradigms such as LNT are questioned (bystander effects), where members of the public and patients interact actively www based, where the attention is drawn on ambiguities in values and where controversial communication is fed by media polarisation. Amazing bio-monitoring opportunities confront expert beliefs, regulatory concepts and responsibilities in health care and are opening new perspectives for multi-factorial epidemiology. Dose as unique risk indicator is no longer self-evident.
Based on the new evidence, radon risk requires stricter standards. However, hygiene should be reformulated to integrate *global indoor air quality* at home as well as at work. The *collective* dose, currently threatened to be abandoned, was and is still useful for characterising the impact on public health of radon (as well as for radiology). In the

NORM area, where standard settings are currently driven by utilitarian ethics, *sustainability* checks for long term (radon) health impact should be introduced.
A more *effective* implementation of operational justification of medical exposures and the integration of optimised radiological protection in medical Quality Assurance could allow controlling the detrimental health impact. Paediatrics and pregnancy ask in this respect for particular attention. However, *risk awareness* is the major challenge for the future and gives an ethical dimension to the new digital imaging resolution opportunities.
Radiotherapy as well as other oncology practices are facing late multi-factorial secondary effects (like circulatory diseases). They require better scientific insight but also science based communication skills.
Radiological protection in the future cannot continue to refer to the virtual average individual when *susceptibility* is demonstrated.
More generally, a major issue is the capacity of taking into account, without undue delay, new relevant data emerging from ongoing research and having a potential impact on public health in situations involving a risk from exposure to ionizing radiation – as for example the new data regarding the risk of radiation induced circulatory diseases. In this context, the European Commission organises every year, in cooperation with the Group of Experts referred to in Article 31 of the Euratom Treaty, a scientific seminar (called RIHSS seminar, for "*Research Implications o*n Health Safety Standards") to discuss in depth relevant issues emerging from ongoing research. The aim is to identify the potential implications on the European Basic Safety Standards of recent research results and to take this into account *in due time*, while debating on the need of a precautionary approach, if uncertainties are present (which is often the case).
*Risk communication*, as difficult search for transparency (RISCOM), should not only disclose technical black boxes and messages but demonstrate a respectful approach of the different perceptions. Perception as impression of a health risk reality is not only a characteristic of lay people. The mental construct of experts needs attention as well. Ethical guidance studied by think tanks (such as PISA in Belgium) and elaborated by IRPA could help to better distinguish the common good and to manage conflicts of interests as experienced in Health Councils. IRPA recently launched stakeholder engagement in radiological protection and successful experiences with local communities open new perspectives. They are based on sociological partnership innovations, mutual respect and considerations of distributive justice in decision making. Such new risk governance processes join prudent precaution strategies as put forward by EEA and the Dutch Health Council. They could facilitate to transform public health opportunities into real perspectives. Precaution requires the systematic specification of uncertainties. This is not as evident in expert culture as scientific method requires. Moreover it takes into account ambiguities related to *value judgements*. This extends the scope of risk assessment and management. For example, in the radiological protection system, where ALARA can be considered as a precursor of precaution, an ecosystem approach is still missing.
Our scientific progress in radiological protection needs a new *transdisciplinary* framing of complexity where social sciences and humanities are more actively involved to complete scientific insight.

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# A large-scale gene expression database on the effect of low doses of radiation: a systems biology approach.

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## Abstract

Current radiation protection regulatory limits are based on the linear non-threshold theory using epidemiological data from atomic bombing survivors. Recent studies sparked debate on the validity of the theory, especially at low doses. Recent advances in molecular biology have shown that different genes and pathways might be triggered by low doses and by high doses of ionising radiation. Identifying the genes and pathways involved in the response to low doses is therefore critical for a better prediction of a possible clinical outcome following radiation exposure.

The increasing interest in the effect of low doses of radiation coincides with the breakthrough in the development of new high-throughput technologies in molecular biology. The microarray technology allows simultaneous measurement of the expression of thousands of genes. As gene expression is the predominant level controlling cell functioning, this technology has become a powerful tool to measure the impact of low doses of radiation.

A major challenge is how to integrate all data resulting from a wide range of experiments and use them to improve our global understanding of the general molecular response of a cell after radiation exposure to low doses. Therefore, we organized into one microarray compendium all radiation expression studies performed within our laboratory. In total, our compendium comprises 233 arrays representing 89 different biological conditions. Applying a systems biology approach on these data will shed light on the relationship between gene expression and different parameters like dose, tissue and organism. Additionally, identification of pathways triggered upon low doses of radiation might open new opportunities towards biodosimetry and appropriate regulation regarding medical exposure and intrinsic radiation sensitivity.

## Introduction

The last decade, molecular biology has been revolutionized by the development of many high-throughput technologies *e.g.* in DNA sequencing, gene expression analysis, electrophoresis, and mass spectrometry. A major advancement herein was the invention of microarrays allowing the transcriptional analysis of thousands of genes in a single experiment. This technological progress now allows analyzing simultaneously the expression of genes at a genome-wide scale. The usage of this technology is certainly not new, as different research groups – including ours - already used this technology to study the influence of radiation on different tissues like blood, brain, liver, kidney, thyroid and others (Amundson et al. 2000, Franco et al. 2005, Paul and Amundson 2008, Pawlik et al. 2009, Tachiiri et al. 2006, Taki et al. 2009, Zhao et al. 2006).

However, to our knowledge it is the first time that a systematic approach is developed to analyse a large and diverse compendium of microarray data using a systems biology approach. Over the last three years, a large number of microarray experiments using Affymetrix technology were performed within the radiobiology group of the Belgian Nuclear Research Center (SCK•CEN), exposing different tissues from human and mouse origins to various doses of ionising radiation (ranging from 0.025 Gy to 8 Gy of X-rays). This resulted in a total of 233 arrays, representing 89 different conditions. The aim of this study is to combine the knowledge present in all these data sets and explore the influence of different parameters (species, tissue, dose) on the genome-wide transcription profiles. In a first stage, a high-level analysis of the data is performed, applying traditional data mining techniques, and exploring the clustering of the different microarray data in the light of the here above mentioned parameters. In a second stage, the data are analysed at the functional level by classifying them based on their annotation, and mapping the gene expression data on existing pathways in order to identify new pathways triggered upon ionizing radiation.



## Material and methods

### Data sets

All samples from various organisms (mice or men) and various tissues (blood, thyroid, brain and embryo) were irradiated using X-rays ranging from 0.025 Gy to 8 Gy with a Pantak HF420 RX machine operating at 250 keV, 1.5 or 15 mA, 1 mm Cu filtration and a dose rate of 0.375 Gy/min. Dosimetry was performed on a regular basis with a 0.6 $cm^3$ ionisation chamber (NE 2571), which was connected to a dosemeter (Farmer dosemeter 2570). The chamber was placed in parallel to the irradiated mouse cages. Dose homogeneity was evaluated as being <1.5%. From all samples, RNA was extracted and converted to biotin-labelled cDNA, which was hybridized to GeneChip® Human Gene 1.0 ST Array and Mouse Gene 1.0 ST Array (Affymetrix, Santa Clara, USA) for human and mouse samples respectively (Table 1).

**Table 1. Overview of microarray data.**

| Species | Tissue | Doses (Gy) | # Arrays | # Conditions |
|---|---|---|---|---|
| Human | Blood | 0.1, 1 | 60 | 30 |
| Human | Thyroid | 0.0625, 0.5, 4 | 12 | 4 |
| Mouse | Thyroid | 0.025, 0.05, 0.0625, 0.1, 0.5, 1, 4, 8 | 86 | 30 |
| Mouse | Embryonic brain | 0.1, 0.2, 0.5, 1 | 37 | 10 |
| Mouse | Whole embryo (early gastrula) | 0.2, 0.4 | 38 | 15 |
| | | **Total** | **233** | **89** |

#### Data preprocessing

Raw Affymetrix data were preprocessed using the “Affy” package (version 1.22.0) in BioConductor (version 2.4) as follows: 1) background correction based on the Robust Multichip Average (RMA) convolution model (Irizarry et al. 2003), 2) quantile normalization to make expression values from different arrays more comparable (Bolstad et al. 2003), 3) summarization of multiple probe intensities for each probeset to one expression value per gene using RMA (Irizarry et al. 2003). To test for differential expression between the different irradiated conditions and the reference conditions (no irradiation) we used the Bayesian adjusted *t*-statistics as implemented in the “LIMMA” package (version 2.18.0) (Smyth 2004). P-values were corrected for multiple testing using the Benjamini and Hochberg’s method to control the false discovery rate (Benjamini and Hochberg 1995).

#### Statistical and data mining applications

All statistical and data mining analyses like principal component analysis, correlation analysis and hierarchical clustering were performed with “Stats” package within the statistical software R (version 2.9.0).

#### Differentially expressed genes and overlapping gene sets

In order to identify differentially expressed genes, a fixed cutoff on the fold change of 1.5 was used. Statistical significance of the overlap of differentially expressed genes between different experiments was calculated using the hypergeometric distribution. This distribution allows calculating the overlap of genes between two conditions, taking into account the number of differentially expressed genes in both conditions separately.



#### Functional enrichment

A gene set enrichment analysis (GSEA) determines to which extent a specific gene set is associated with a particular pathway or biological function. In order to calculate the statistically significant enrichment of a set of differentially expressed genes towards a specific pathway or biological process, the KEGG (Kanehisa et al. 2010) and Gene Ontology (Ashburner et al. 2000) databases were used respectively. This analysis was performed using the “GOstats” package (version 2.10.0) (Falcon and Gentleman 2007) of BioConductor (version 2.5)

### Results

#### Data preprocessing

All data were preprocessed as explained in the “Material and methods” section. The relative expression of genes was measured by comparing the gene expression in irradiated tissues with gene expression in control samples of the same tissue. This prevented that we would only find tissue-specific genes when comparing different experiments, which would not be related to irradiation but rather to the intrinsic function of the cells in specific tissues. By recalculating the expression levels to fold changes (*i.e.* the ratio of the expression level in irradiated tissues over the expression level in control non-irradiated samples), the number of conditions was reduced from 89 to 63 experiments. By applying a variation filter, all genes showing minimal variation across different experiments were excluded.

**Classification of radiation expression profiles**

Using Principal Component Analysis (PCA), a first approach focused on the general similarities or dissimilarities between transcription profiles of different experiments. PCA is an algorithm that reduces the dimensionality of the data while retaining most of the variation in the data set. Experiments grouping closely together in a PCA biplot can be considered as sharing a similar transcriptional response after irradiation.

The extreme position of two thyroid irradiation experiments is a first emerging pattern (see Figure 1). The position of these experiments on the PCA plot could be more easily explained by the experimental setup, than by an effect of dose or tissue. Indeed, in contrast to other irradiation experiments where messenger RNA (mRNA) was isolated at most a few hours after irradiation, the mice in those experiments were irradiated at a specific time point, and the mRNA of the thyroid was isolated after 9 or 18 months respectively.

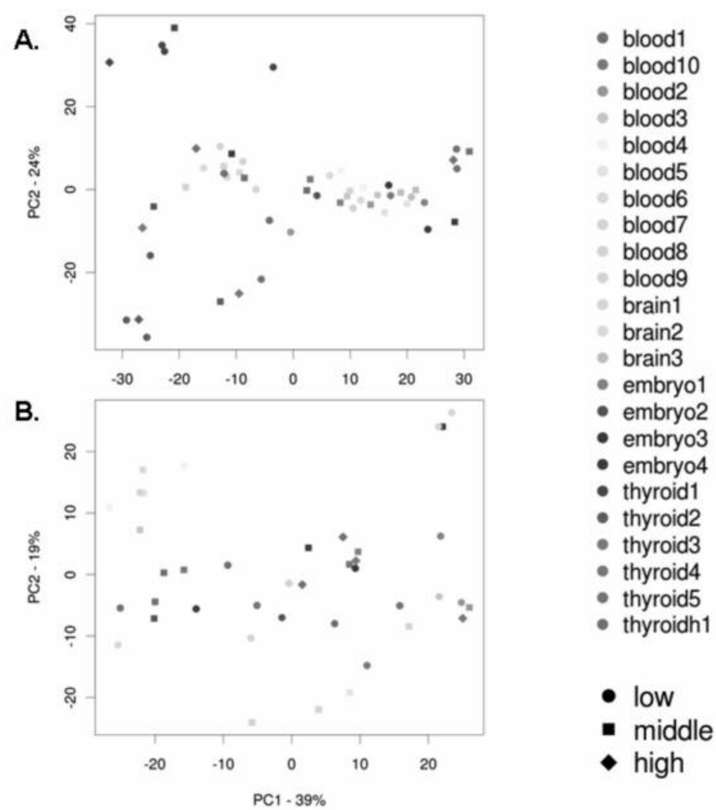



**Fig. 1. PCA biplot of A) all irradiation experiments. B) all irradiation experiments with exception of long-term thyroid experiment (mRNA extraction after 9 [thyroid1] and 18 months [thyroid2]). Colour codes represent the different experiments, symbols indicate the radiation dose: low (<0.2Gy), middle (0.2Gy – 1Gy) and high (> 1Gy)**

As a second observation, no tight clustering was found for the parameter of dose. This is remarkable as the data set included samples irradiated over a wide dose range, varying from low doses as 0.025 Gy up to doses as high as 8 Gy. The same conclusion could be drawn concerning the species-effect: no clear distinction could be made between the gene expression profiles originating from human or mouse samples. On the contrary, all microarray data seemed to cluster together rather on the type of experiment, even when irradiated with largely different radiation doses. For example considering the arrays measuring the gene expression after irradiation of the thyroid followed by immediate extraction of mRNA, all arrays cluster tightly together regardless irrespective of the irradiation dose (0.1 or 4Gy). Such effect could hardly be explained by an artefact resulting from a batch effect, since experiments performed with the same settings but at time points lying at least one year from each other, tend to cluster together as observed in the irradiated human blood samples.

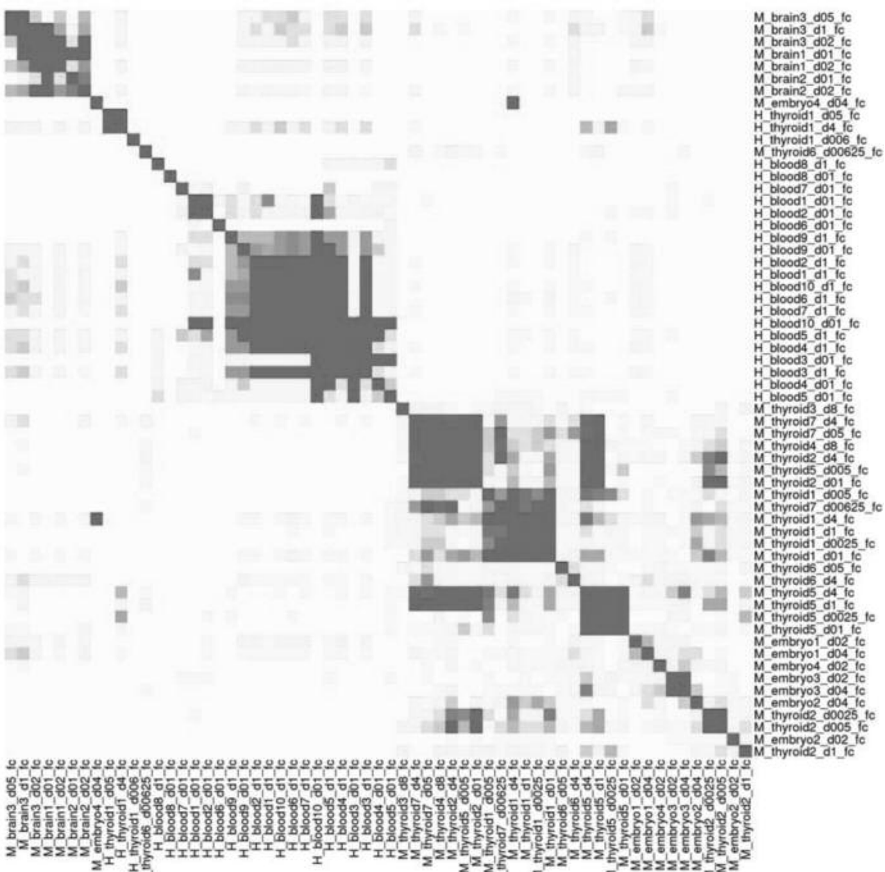



**Fig. 2. Clustering of 63 experiments based on the statistical significance (P-value) of the number of overlapping genes shared between two experiments. The red colour indicates a highly significant overlap, the white colour means no significant overlap.**

### Differentially expressed genes

Whereas previous high-level analysis was based on simultaneous analysis of thousands of genes with the highest variance over the different conditions, analysis of the differentially expressed genes within the various conditions allows interpretation from an alternative angle. Taking into account the number of upregulated genes with a cutoff on the fold change of 1.5, the highest number of differentially expressed genes was observed for the thyroid irradiated samples with late mRNA extraction (after 9 and 18 months respectively) and for a subset of irradiated embryo (gastrula stage) samples. The former observation is in agreement with the PCA results reported in the previous paragraph. When taking into account the overlap of differentially expressed genes between various conditions, clustering based on the statistical significance of the overlap was done according to the tissue type (blood, brain, thyroid, and embryo) (Figure 2). These results suggest the presence of a tissue-specific transcriptional response towards radiation. From a species-specific point of view, the number of overlapping genes between human and mouse irradiated thyroid is very limited.

Focussing on the blood samples, a significant increase in the number of differentially expressed genes is observed when increasing the radiation dose from low (0.1 Gy) to high (1 Gy). Moreover, taking into account the overlap of differentially expressed genes between all blood samples, a tight grouping of the 1 Gy samples is observed, while a less robust overlapping set of genes is observed for the lower dose (0.1 Gy).



### Functional interpretation of radiation response

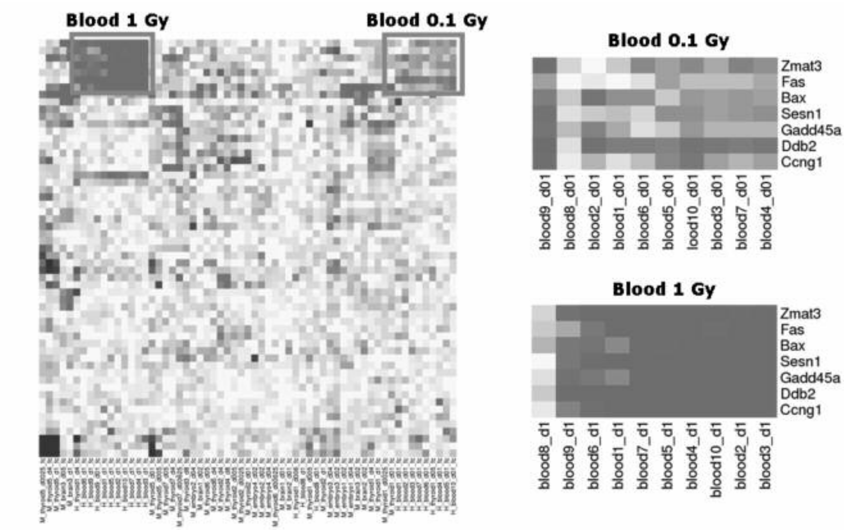
Using a gene set enrichment strategy, functional enrichment of the differentially expressed genes in all irradiation experiments was performed using the KEGG pathway database (Kanehisa et al. 2010) and the Gene Ontology classification system.

No KEGG pathway or GO biological process could be found to be commonly enriched in all (or a majority of) experiments. This corresponds with the observation of differentially expressed genes being tissue specific, as discussed in previous paragraph. As such, clustering based on functional enriched categories results in grouping of the experiments based on tissue.

The most significantly enriched KEGG pathways (cut-off on p-value on 0.05) were the p53 signalling (KEGG:04115), the nucleotide excision repair (KEGG:03420) and the cell cycle (KEGG:04110) pathways, enriched respectively in 28, 22 and 13 out of the 63 experiments. The first pathway was significantly enriched in roughly all irradiated blood samples (0.1 Gy and 1 Gy) and almost all irradiated embryonic brain samples (0.2 Gy and 0.4 Gy) (Figure 3.A). With regard to the blood samples, a clear dose dependency could be observed. The other two pathways could not be assigned to a specific subset of experiments. Remarkably, the apoptosis pathway (KEGG: 04210) was only enriched in four experiments. However, zooming in onto the individual expression values of the genes belonging to this pathway revealed an interesting pattern: a consistent set of genes was found to be upregulated within the thyroid experiments where extraction of mRNA was performed after several months compared with the non-irradiated sample at the same time (Figure 3.B).

Similarly, the most enriched GO biological processes were related to DNA damage and repair (e.g. GO:0006974, GO:0006281) and cell cycle (e.g. GO:0051726, GO:0007067), all enriched in at least 14 out of the 63 experiments, with a maximum of 24 for response to DNA damage stimulus (GO:0006974). The response to DNA damage stimulus was mostly enriched in the irradiated blood samples, as well as in a subset of the embryonic experiments.

A.






B.

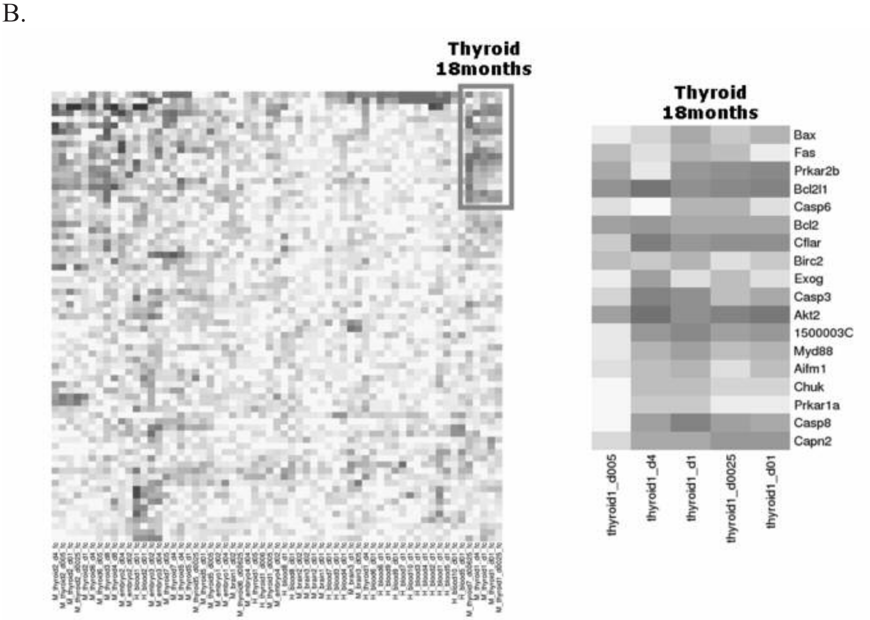



**Fig. 3. Heatmap of expression of all genes belonging to A) the p53 signalling (KEGG:04115) and B) the apoptosis (KEGG:04210) pathways. For the p53 signalling pathway, a subset of genes appears to be upregulated in a dose dependent manner in the blood samples. For the apoptosis pathway, a set of genes is upregulated in the long-term experiment with mRNA extraction 18 months after irradiation with low and high doses.**

## Discussion

The advances in high-throughput technologies like microarrays have revolutionized the field of molecular biology. This microarray technology has already been used extensively to study the effect of low and high doses of ionising radiation at the transcriptional level. However, until now most studies have focussed on the impact of radiation on single specific tissues. In this paper, a more systematic approach was applied to study the radiation effect over various parameters.

A first remarkable observation in the PCA analysis was the aberrant transcriptional profile of two long-term experiments where mRNA was extracted from mouse thyroid tissue several months after low and high doses of irradiation. This deflected transcriptional behaviour was confirmed by the increasing number of upregulated genes in this long-term experiment compared to the acute stress experiment. These data obtained on mouse thyroid tissues are in line with the observation of Fält *et al.* (2003) who noticed that the number of differentially expressed genes increased dramatically with increasing culture time. In their experiment, primary human lymphocytes were irradiated, and mRNA was extracted at different time points (7, 17 and 55 days), showing a clear increase with the time in the number of modulated genes. Moreover, while the changes in the pattern of gene expression reported by Fält *et al.* (2003) occurred after a high radiation dose (3 Gy), the observations in the present study allow to extend their conclusions to doses as low as 0.05 and 0.025 Gy. In contrast with their study in which a limited overlap of genes was found between the immediate and long-term data, our results point towards a significant overlap with the acute response based on the number of upregulated genes shared between short- and long-term experiments. Interestingly, one of these long-term experiments (18 months) showed a significant enrichment of apoptosis related genes when compared to gene expression in a non-irradiated mouse of the same age.



Based on analysis by PCA, irradiation experiments are grouped together according to the experiments rather than by the irradiation dose. Accordingly, clustering based on the number of overlapping upregulated genes shows clear links with the tissue origin. As such, the gene expression in irradiated biological material seems to be tissue-specific rather than dose-specific. A similar, small scale analysis comparing two sets of differentially expressed genes after irradiation of kidney and brain with a high dose of 10 Gy, basically resulted in the same conclusion: only a very limited number of overlapping genes could be identified (Zhao et al. 2006), also pointing towards a tissue-specific response. Similarly, Pawlik *et al*. (2009) found that the expression profile of irradiated liver tissue correlated only to a small extent to the one in other tissues.

As a consequence of the tissue specificity of the transcriptional response after irradiation, no common pathway could be identified yet over different experiments or doses. However, certain pathways e.g. related to p53 signalling, cell cycle, DNA damage and repair were activated in a wide range of experiments, but mainly in the irradiated blood samples. This manifest activation of pathways related to DNA repair and cell cycle is probably related to the increased sensitivity of haematopoietic cells to radiation. Moreover, for the p53 signalling pathway, a dose specific transcriptional response was observed within irradiated blood samples, which is in agreement with similar results by other research groups aiming at identifying a potential set of radiation responsive biomarkers in blood (Dressman et al. 2007, Paul and Amundson 2008).

However, a new trend in disease classification also incorporates pathway information in order to classify diseases based on the activity of entire pathways instead of expression levels of individual genes (Lee et al. 2008, Svensson et al. 2006). Therefore, based on this and previous studies, the p53 signalling cascade might be a good candidate to be used as pathway-based biodosimetry classifier. However, the absence of a non-perturbed basal expression profile of this pathway in biodosimetry application is still a challenging issue (Paul and Amundson 2008).

## Conclusions

First, results presented here point towards an important tissue-specific aspect in response to ionzing radiation. Secondly, gene expression results confirm the importance of performing studies on the long-term effect of radiation, as differential expression increased with longer post-irradiation times.

In this paper, the data are only interpreted from a bird's-eye view. However, a more thorough analysis is necessary and currently under progress. Generally, our studies point towards subtle but undeniable changes in gene expression. Therefore, an important future challenge is extracting these subtle changes in a statistically significant way by exploiting additional systems biology tools.

## Acknowledgements

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# Dose-Area-Product to Effective Dose in Interventional Cardiology and Radiology

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## Abstract

The implementation of the European Directives introduced a number of new tasks to the radiology departments. It was stated that the determination of radiation doses are an important issue in the framework of radiation protection of the patient. And special attention is given to high-dose procedures, like interventional cardiology (IC) and radiology (IR).

Radiological departments are legally obliged to register dose-area-product (DAP) values for every patient undergoing IR and IC procedures. A large national multi-centre project on dose evaluations for IC and IR performed a few years ago, showed that centers with similar average DAP-values, could still result in significant different average effective dose values. Simply register DAP-values is therefore not always the only and most adequate tool for optimization at IC and IR. The additional calculation of effective dose could enable medical physicists to determine and evaluate dose values which will more connect to radiation risk evaluation, if necessary.

In the past conversion coefficients (CCs) from DAP to effective dose have been calculated systematically for different anatomical regions and projections for conventional radiological procedures. The use of these published CCs, however are not appropriate for the calculation of effective dose for IC and IR. The irradiated field sizes deviate from those in conventional radiology. Moreover, the requested CCs according to the beam qualities used for these complex procedures are not included in the published conversion tables. In the framework of patient dose optimization, however, there is a need to the availability of systematic tables with CCs who will allow the calculation of the effective dose for the complete offer of IC and IR procedures.

In this paper is described how the CCs are calculated for the most common and used radiation fields in IC and IR. The systematic tables with CCs can be obtained at the Federal Agency of Nuclear Control (www.fanc.fgov.be).

## Introduction

The implementation of the European Directives (97/43/Euratom) into the Belgian legislation introduced a number of new tasks to the radiology departments. It was stated that the determination of radiation doses are an important issue in the framework of

radiation protection of the patient. And special attention is given to high-dose procedures, like interventional cardiology (IC) and interventional radiology (IR).
The need of dose auditing and patient dosimetry is emphasized in relation to optimization of radiological procedures. Moreover, radiological departments are legally obliged to register dose-area-product (DAP) values for every patient undergoing IR and IC procedures. As these procedures were considered as a priority, the Belgian Federal Agency of Nuclear Control financed a very large national multi-centre project on dose evaluations for IC and IR procedures a few years ago (Bosmans 2006). From this project, however, we learned that only DAP registration for optimization purposes is not always adequate. Measurements in almost 20 hospitals showed that centers with similar average DAP-values, could still result in significant different average effective dose values. This was caused by a different use in copper filtration during the procedures. With complex interventional procedures the risk of deterministic skin damage to the patient exists. To prevent this, the use of additional filtration is recommended. At new modern equipment, the amount of filtration is automatically introduced by the system, depending on the procedure and the patient. More and more also the use of other types of filtration is investigated for these kinds of procedures.
Simply register DAP-values is therefore not always the only and most adequate tool for optimization at interventional procedures. The additional calculation of effective dose could enable medical physicists to determine and evaluate dose values which will more connect to radiation risk evaluation, if necessary.
The effective dose can be calculated by multiplication of the registered DAP-values and appropriate conversion coefficients (CCs). In the past such coefficients have been calculated systematically for different anatomical regions and radiation projections for conventional radiological procedures. The use of these published CCs, however are not appropriate for the calculation of effective dose for IC and IR procedures. The irradiated field sizes and regions deviate from those in conventional radiology. Moreover, the requested CCs according to the beam qualities used for these complex procedures are not included in the published conversion tables. In literature (Kemerinck et al. 1999), (Schultz et al. 2003), (Kemerinck et al. 2003), (Kicken et al. 1999) some CCs can be found for specific interventional procedures, calculated according to the need of the specific study. In the framework of patient dose optimization, however, there is a need to the availability of systematic tables with CCs who will allow the calculation of the effective dose for the complete offer of IC and IR procedures, if needed.
In this paper is described how the CCs are calculated for the most common and used radiation fields in interventional cardiology and interventional radiology. The systematic tables with conversion coefficients can be obtained from the authors or at the Federal Agency of Nuclear Control (www.fanc.fgov.be).



## Material and methods

### Choice of Monte Carlo code

The Monte Carlo code that is used in this project is *MCNP-X (v 2.5.0)* (Pelowitz et al. 2005). This code has been used frequently in medical physics and allows reliable dose calculations for photon radiation sources. The calculations are performed by 2 institutes: the department of medical Physics of the University of Ghent (UGent) performed the necessary calculations for the IC procedures and the Belgian Nuclear

Research Centre (SCK•CEN) performed all calculations for the IR procedures. The same and most recent libraries, containing all cross sections and material data, are used by both institutes.

**X-ray source definition**

An important input parameter for the Monte-Carlo simulations is the X-ray source design. Different possibilities exist to model an X-ray source in the *MCNP-X* environment. A small intercomparison with a simplified geometry showed that the approach of both institutes resulted in the same values.
With respect to the definition of the X-ray spectrum, the "IPEM-78 – Catalogue of Diagnostic X-ray Spectra" (Cranley 1997) was used. This publication provides a valuable software tool for generating X-ray spectra based on parameters kVp, filtration, anode angle and kV signal ripple. In clinical practice a large variety of X-ray spectra are being used. For the interventional applications in this project, kVp-values typically range from 60 to 130 kVp. Filtrations can be based on a single aluminium filtration (2.5 – 6 mm Al) or on a combination with copper filtration (0.1 – 0.9 mm Cu). As it is practically impossible to simulate all possible kV/filtration combinations for all clinical projections, an alternative approach is used within the project.
We have decided to use X-ray spectra definitions based on half-value layers (HVL). In fact, different kVp/filtration combinations may result in the same HVL-values as illustrated in figure 1.



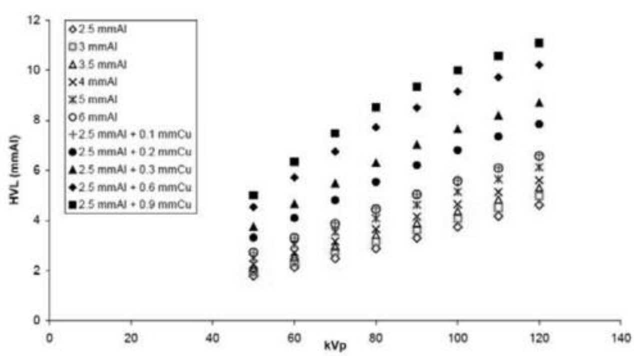


**Fig. 1. Half-value layer values for different kVp and filter combinations**

Therefore, simulations based on a HVL-range that is clinically relevant would be interesting. In order to test the feasibility of this approach, Monte Carlo calculations were performed on a mathematical anthropomorphic phantom using different kVp/filtration settings – all resulting in the same HVL. The latter simulations showed that DAP-to-effective dose conversion coefficients simulated with the "HVL method" deviated maximum 5% of the values simulated with the exact spectrum.
For interventional radiology procedures, an anode angle of 14° was used, whereas for interventional cardiology procedures the spectra are generated based on an anode angle of 9°.

### X-ray fields and projections

The X-ray field sizes and projections are other important factors to be taken into account for the simulations. In table 1 and 2, an overview of typical clinical settings is given for IR and IC, respectively.

**Table 1. X-ray fields and projections considered for interventional radiology procedures**

| | Application | Projection | Field size at image intensifier (cm) |
|---|---|---|---|
| 1 | Head | LAO[1] 45° | 28 |
| 2 | Head | RAO[2] 45° | 28 |
| 3 | Head | PA[3] | 28 |
| 4 | Head | LLAT[4] | 28 |
| 5 | Head | RLAT[5] | 28 |
| 6 | Neck | LAO 45° | 28 |
| 7 | Neck | RAO 45° | 28 |
| 8 | Neck | PA | 28 |
| 9 | Thorax | LAO 45° | 28 |
| 10 | Thorax | RAO 45° | 28 |
| 11 | Abdomen | LAO 45° | 40 |
| 12 | Abdomen | RAO 45° | 40 |
| 13 | Abdomen | PA | 40 |
| 14 | Abdomen | LLAT | 40 |
| 15 | Abdomen | RLAT | 40 |
| 16 | Pelvis | LAO 45° | 40 |
| 17 | Pelvis | RAO 45° | 40 |
| 18 | Pelvis | PA | 40 |
| 19 | Upper legs | PA | 40 |
| 20 | Lower legs | PA | 40 |

[1]LAO: Left Anterior Oblique / [2]RAO: Right Anterior Oblique
[3]PA: Posterior-Anterior / [4]LLAT: Left Lateral
[5]RLAT: Right Lateral



**Table 2. X-ray fields and projections considered for interventional cardiology procedures**

| | Projection RAO/LAO | Projection CRAN[1]/CAUD[2] | Field size at image intensifier (cm) |
|---|---|---|---|
| 1 | RAO 30° | CAUD 25° | 17 |
| 2 | RAO 30° | CAUD 0° | 17 |
| 3 | RAO 30° | CRAN 25° | 17 |
| 4 | LAO 45° | CRAN 25° | 17 |
| 5 | LAO 45° | CAUD 0° | 20 |
| 6 | LAO 45° | CAUD 25° | 17 |
| 7 | LAO 90° | CAUD 0° | 17 |
| 8 | LAO 0° | CAUD 25° | 17 |
| 9 | LAO 0° | CAUD 0° | 20 |
| 10 | LAO 15° | CAUD 0° | 17 |
| 11 | LAO 30° | CAUD 0° | 17 |
| 12 | RAO 30° | CAUD 0° | 20 |

[1]CRAN: cranial / [2]CAUD: Caudal

### Choice of anthropomorphic phantom

In view of the new recommendations of ICRP (ICRP 2008) and the definition of additional radiation sensitive organs (salivary glands, adipose tissue, connective tissue, extra thoracic airways, heart wall and lymphatic nodes) for the calculations of the effective dose, the choice of an anthropomorphic phantom was not straightforward. Current mathematical phantoms are not appropriate for calculating the revised

definition of the effective dose as they do not contain these 'new' organs. The choice of a voxel-phantom, for which a larger amount of organs are segmented, seemed more appropriate. At the start of the project, the standard ICRP voxel phantoms were not available. Other appropriate and available phantoms with standard dimensions are the MAX06 and FAX06 phantoms (Kramer et al 2006). These are very detailed phantoms constructed from voxels of 1.2 x 1.2 x 1.2 $mm^3$. The total MAX06 phantom consists of 474 x 222 x 1359 = 143.004.582 voxel elements. All necessary organs are present and realistically segmented. However, when this phantom is converted into a format suitable for *MCNP-X*, input files are created from 20 to 30 MB. Such large input files require a lot of computer memory and some test calculations demonstrated that this memory capacity is not available in both UGent and SCK•CEN. Hence, the calculations could not be performed with these phantoms.
A large family of voxel phantoms is available at the Helmholtz Zentrum München – German Research Center for Environmental Health and we decided to test the Golem (Zankl, Wittman 2001) and Laura phantoms. These phantoms have body characteristics similar to the reference persons. Golem is constructed from voxels of 2.08 x 2.08 x 8.0 $mm^3$. His height is 176 cm and weight 68.9 kg. Laura is constructed from 1.875 x 1.875 x 5.0 $mm^3$ voxels. Her height is 167 cm and weight 59 kg. A cross section of both phantoms is given in figure 2. Both phantoms have a realistic number of voxels that can be handled by *MCNP-X*. Test runs showed that CPU time of maximum 130 minutes are needed for the transport of 10E06 particles (for F6 and *F8 tallies) on the computer clusters of UGent and SCK•CEN, resulting in relative errors for the organs in the radiation field lower than 1%.



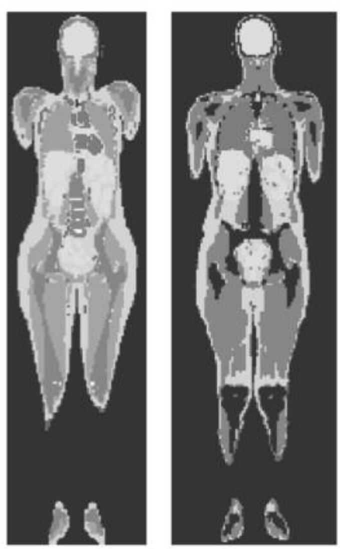

**Fig. 2. Cross sections of the LAURA (left) and GOLEM (right) voxel phantoms**

As red bone marrow and bone surface are not segmented within the Golem/Laura phantoms, correction factors to the mean skeleton dose were calculated based on the material composition and density of red bone marrow, yellow bone marrow and cortical bone structures throughout the human body (Zankl et al. 2007). For the gall bladder and small intestine no distinction is made between wall and contents in the Golem phantom. Golem does not have breast (glandular tissue) and salivary glands and both phantoms do not have oral mucosa nor lymphatic nodes. The dose to the oral mucosa was approximated by the dose to the tongue and the dose to the lymphatic nodes was approximated by that to other distributed tissue, like muscle or adipose tissue.

## Results

For interventional radiology, the following spectra are considered:

- Head: from 80 to 100 kVp in steps of 10 kVp
  from 3 mm Al to 6 mm Al in steps of 1 mm
  from 0 to 0.3 mm Cu in steps of 0.1 mm
  This resulted in a HVL range from 3.5 – 8.5 mm Al
- Neck: from 60 to 100 kVp in steps of 10 kVp
  from 3 mm Al to 6 mm Al in steps of 1 mm
  from 0 to 0.3 mm Cu in steps of 0.1 mm
  This resulted in a HVL range from 2.5 – 8.5 mm Al
- Thorax, abdomen and pelvis: Idem as Neck
- Legs: from 60 to 80 kVp in steps of 10 kVp
  from 3 mm Al to 6 mm Al in steps of 1 mm
  from 0 to 0.3 mm Cu in steps of 0.1 mm
  This resulted in a HVL range from 2.5 – 6.5 mm Al



Spectra are considered in steps of 1 mm Al HVL for both the Golem and the Laura phantoms and each projection as given in table 1. This resulted in a total number of 262 calculations.

For interventional cardiology, the following spectra are considered:

- Thorax: from 60 to 130 kVp in steps of 10 kVp
  from 0 to 0.9 mm Cu for 2.5 mmAl
  from 0 to 0.3 mm Cu for 3 and 4 mm Al
  in steps of 0.1 mm Cu en 1 mm Al
  This resulted in a HVL range from 2.5 to 11.5 mm Al.

For both phantoms and all projections considered in table 2, this resulted in a total number of 240 calculations.

Before the systematical calculation campaign started, a final intercomparison was performed between UGent and SCK•CEN. This should reveal possible differences in processing the voxel-based data. The simulations for this intercomparison was based on the same input file (PA thorax irradiation of the Golem phantom, field size 520 $cm^3$, 70 kVp, 4 mm Al and 10E06 particles). The results are presented in table 3.

The results show an excellent agreement between the SCK•CEN and UGent simulations with respect to the effective dose/DAP. Individual organ doses show small deviations smaller than 1%. The latter simulation run had a CPU time of 55 min for the SCK•CEN simulations and of 79 min for the UGent simulations.

The results of the systematic calculation campaign are given in organ dose/DAP for both phantoms separately and effective dose/DAP for both phantoms together using the new ICRP103 organ weighting factors. The conversion coefficients between DAP and effective dose are given in table 4a and b for interventional radiology and interventional cardiology, respectively. All tables, including the DAP-organ dose conversion coefficients can be obtained from the authors and from the Federal Agency of Nuclear Control (www.fanc.fgov.be).

**Table 3. Results of an intercomparison for one typical input file**

| | organ dose D/DAP SCK/CEN [Gy/Gy cm²] | organ dose D/DAP UGent [Sv/Gy cm²] |
|---|---|---|
| RBM | 1,96E-05 | 1,98E-05 |
| colon | 7,56E-06 | 7,55E-06 |
| lung | 1,30E-04 | 1,31E-04 |
| stomach | 9,93E-05 | 9,92E-05 |
| bladder | 1,23E-07 | 1,22E-07 |
| oesophagus | 2,39E-04 | 2,39E-04 |
| gonads | 1,47E-08 | 1,45E-08 |
| liver | 1,04E-04 | 1,03E-04 |
| thyroid | 1,03E-04 | 1,04E-04 |
| bone surface | 4,46E-04 | 4,50E-04 |
| brain | 1,53E-06 | 1,54E-06 |
| kidneys | 1,87E-05 | 1,86E-05 |
| salivary glands | 4,41E-08 | 4,39E-08 |
| skin | 4,19E-05 | 4,20E-05 |
| remainder: | 8,99E-05 | 8,95E-05 |
| effective dose/DAP | 6.72 Sv/Gycm² | 6.72 Sv/Gycm² |



**Table 4a. DAP to effective dose conversion coefficients for interventional radiology procedures**

| | HVL (mm Al) | | | | | | |
|---|---|---|---|---|---|---|---|
| **Effective dose (mSv/Gycm²)** (*) | **2,5** | **3,5** | **4,5** | **5,5** | **6,5** | **7,5** | **8,5** |
| Abdomen PA | 0,089 | 0,136 | 0,169 | 0,200 | 0,224 | 0,259 | 0,283 |
| Abdomen LAO 45° | 0,074 | 0,102 | 0,135 | 0,155 | 0,179 | 0,202 | 0,219 |
| Abdomen RAO 45° | 0,068 | 0,100 | 0,117 | 0,140 | 0,161 | 0,187 | 0,204 |
| Abdomen LLAT | 0,205 | 0,259 | 0,320 | 0,360 | 0,380 | 0,428 | 0,456 |
| Abdomen RLAT | 0,118 | 0,158 | 0,195 | 0,217 | 0,244 | 0,266 | 0,286 |
| | | | | | | | |
| Head PA | - | 0,036 | 0,043 | 0,050 | 0,055 | 0,063 | 0,068 |
| Head LAO 45° | - | 0,036 | 0,045 | 0,052 | 0,059 | 0,065 | 0,070 |
| Head RAO 45° | - | 0,039 | 0,046 | 0,053 | 0,060 | 0,067 | 0,073 |
| Head LLAT | - | 0,045 | 0,056 | 0,063 | 0,066 | 0,075 | 0,081 |
| Head RLAT | - | 0,049 | 0,060 | 0,066 | 0,074 | 0,081 | 0,086 |
| | | | | | | | |
| Upper legs PA | 0,022 | 0,028 | 0,039 | 0,048 | 0,055 | - | - |
| Upperlegs-knees PA | 0,004 | 0,005 | 0,006 | 0,007 | 0,008 | - | - |
| Knees-lower legs PA | 0,004 | 0,004 | 0,005 | 0,006 | 0,006 | - | - |
| | | | | | | | |
| Neck PA | 0,044 | 0,065 | 0,079 | 0,093 | 0,103 | 0,118 | 0,129 |
| Neck LAO 45° | 0,056 | 0,071 | 0,088 | 0,099 | 0,111 | 0,123 | 0,131 |
| Neck RAO 45° | 0,061 | 0,079 | 0,092 | 0,105 | 0,118 | 0,130 | 0,139 |
| | | | | | | | |
| Pelvis PA | 0,095 | 0,134 | 0,164 | 0,190 | 0,210 | 0,236 | 0,254 |
| Pelvis LAO 45° | 0,057 | 0,077 | 0,100 | 0,116 | 0,133 | 0,149 | 0,161 |
| Pelvis RAO 45° | 0,059 | 0,084 | 0,099 | 0,118 | 0,134 | 0,154 | 0,167 |
| | | | | | | | |
| Thorax LAO 45° | 0,065 | 0,091 | 0,122 | 0,141 | 0,163 | 0,186 | 0,202 |
| Thorax RAO 45° | 0,052 | 0,079 | 0,093 | 0,113 | 0,131 | 0,156 | 0,171 |

**Table 4a. DAP to effective dose conversion coefficients for interventional cardiology procedures**

| | HVL (mm Al) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Effective dose (mSv/Gycm²) (*)** | **2,5** | **3,5** | **4,5** | **5,5** | **6,5** | **7,5** | **8,5** | **9,5** | **10,5** | **11,5** |
| LAO 0° CAUD 0° | 0,117 | 0,185 | 0,245 | 0,285 | 0,313 | 0,360 | 0,394 | 0,425 | 0,453 | 0,466 |
| LAO 0° CAUD 25° | 0,102 | 0,168 | 0,228 | 0,269 | 0,293 | 0,343 | 0,379 | 0,411 | 0,441 | 0,457 |
| LAO 15° CAUD 0° | 0,123 | 0,196 | 0,261 | 0,305 | 0,334 | 0,386 | 0,424 | 0,458 | 0,490 | 0,505 |
| LAO 30° CAUD 0° | 0,135 | 0,199 | 0,255 | 0,294 | 0,321 | 0,364 | 0,396 | 0,399 | 0,451 | 0,464 |
| LAO 45° CAUD 0° | 0,172 | 0,245 | 0,307 | 0,350 | 0,387 | 0,429 | 0,462 | 0,493 | 0,519 | 0,531 |
| LAO 45° CAUD 25° | 0,105 | 0,169 | 0,218 | 0,252 | 0,278 | 0,314 | 0,342 | 0,367 | 0,389 | 0,400 |
| LAO 45° CRAN 25° | 0,134 | 0,206 | 0,262 | 0,301 | 0,331 | 0,372 | 0,403 | 0,431 | 0,455 | 0,468 |
| LAO 90° CAUD 0° | 0,118 | 0,183 | 0,241 | 0,280 | 0,309 | 0,352 | 0,385 | 0,414 | 0,440 | 0,453 |
| RAO 30° CAUD 0° | 0,176 | 0,254 | 0,320 | 0,365 | 0,404 | 0,448 | 0,484 | 0,517 | 0,545 | 0,555 |
| RAO 30° CAUD 0° | 0,173 | 0,250 | 0,316 | 0,361 | 0,399 | 0,444 | 0,480 | 0,513 | 0,540 | 0,551 |
| RAO 30° CAUD 25° | 0,110 | 0,167 | 0,216 | 0,250 | 0,276 | 0,312 | 0,341 | 0,366 | 0,388 | 0,399 |
| RAO 30° CRAN 25° | 0,140 | 0,210 | 0,271 | 0,312 | 0,345 | 0,389 | 0,423 | 0,454 | 0,481 | 0,492 |

## Discussion

The ICRP standard voxel phantoms REX and REGINA were not available at the time of the study, so instead the phantoms GOLEM and LAURA are used. The dimensions of these phantoms are really close to the standard phantoms, but still some radiosensitive organs were missing, to be able to calculate effective dose according to the new ICRP103 organ weighting factors. One of the organs missing in the GOLEM phantom is the breast. In this study, the 'average' breast dosis for both phantoms for the effective dose calculation only comes from the breast of LAURA. We could consider a breast dosis of zero for GOLEM to calculate the average breast dose, but the authors believe that a larger error is made compared to only consider the breast dose from LAURA.

In general, we do not expect drastic changes for the conversion coefficients when these calculations would be repeated with the standard REX and REGINA phantoms.



## Conclusions

The possibility to calculate organ doses and effective dose from online DAP measurements for interventional radiology and cardiology procedures can be a useful tool and completion for dose optimization purposes. In this project complete and systematic tables with organ dose and effective dose conversion coefficients are calculated from DAP values for these kinds of procedures.

## Acknowledgement

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# Estimating lung cancer risk due to radon exposure in the radon-prone areas of Belgium

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## Abstract
Radon exposure in Belgium is particularly pronounced in the southern part of the country, characterized by a sub-surface composed of highly deformed and fractured (black) shale, schist and quartzite of the Ardenne massif. A national indoor radon measurement campaign (1995-2000) showed that all of the high radon risk areas (where more than 5% of the measured buildings exceed the current Belgian action-level of 400 Bq/m³) were situated within the Ardenne massif, affecting a population of about 380 thousand. For this reason, detailed information, measurement and prevention campaigns have been organized for the local population and municipal authorities. Whereas the national average indoor radon concentration is about 50 Bq/m³, this average increases to about 130 Bq/m³ in the high risk areas. Here, 13% of the houses exceed the action level, affecting more than 50 000 people, and 4% of the houses exceed 800 Bq/m³, affecting more than 15 000 people. In 33% of the dwellings, the design level for new buildings (200 Bq/m³) is exceeded. According to the risk estimates from international epidemiological studies, about 18% of the occurring lung-cancers in the high risk areas (~43 cases on 240 per year) would be due to radon exposure. About 38% of the radon-induced lung-cancers (LC) would occur in the population exposed to more than 400 Bq/m³ (about 30 lung-cancers per year). Comparison of these theoretical values with actual LC statistics of the Belgian Cancer Registry shows a good match between the total number of annual LC in the high risk areas (239 calculated to 240 observed in the period 2004-2005). The correlation between LC incidence rate and average radon concentration however is obscured by the high number of influencing factors (migration, age-distribution, life-habits,…) and the relatively limited population and LC incidence rate. Radon campaigns aim at stimulating house owners and building responsibles to mitigate the radon affected buildings and to apply preventive measures in new buildings. In the high risk areas, preventive reduction of radon exposure to below 200 Bq/m³ should lead to a reduction of the LC incidence rate with 7%.

## Introduction
For the general population, radon is usually the most prevailing source of radiation exposure in the indoor environment (ICRP 60, 1990). The link between radon and lung cancer has been first recognised through miner cohort epidemiological studies (BEIR

IV, 1988; BEIR VI, 1998; UNSCEAR 2000). More recent case-control studies highlight the linear no-threshold relation between lung cancer risk and indoor radon-concentration in dwellings (Darby et al., 2005). In order to efficiently manage the radon exposure, most European countries have adopted a radon action plan, setting out the criteria, strategies and practical aspects of radon controlling activities. The Belgian radiation protection regulation (ARBIS, 2001) foresees the control of radon exposure in workplaces and in dwellings in radon prone areas. A national radon measurement campaign during the 1990's highlighted the occurrence of radon prone areas (defined at that time as municipalities where more than 1% of the dwellings exceed the action level of 400 Bq/m³) in the southern part of the country (Poffijn and Vanmarcke, 1990; Zhu et al., 1998). Ongoing indoor radon measurements led to the classification of the territory into radon regions (Fig. 1) on a national scale and into radon classes on a local scale (Fig. 4). Within the radon prone areas, a specific region shows a high risk of having high indoor radon concentrations. This is the high risk area (HRA, Radon region 2 on figure 1), where more than 5% of dwellings exceed the action level. It is characterised by the occurrence of highly deformed metamorphic rocks of Lower Palaeozoic age. The HRA affects a population of about 380 thousand. If the national action level would be brought to 200 Bq/m³, the population living in the HRA would increase to more than 1.1 million. The measurement campaigns also allowed assessing the radon exposure of the Belgian population (Table 1).



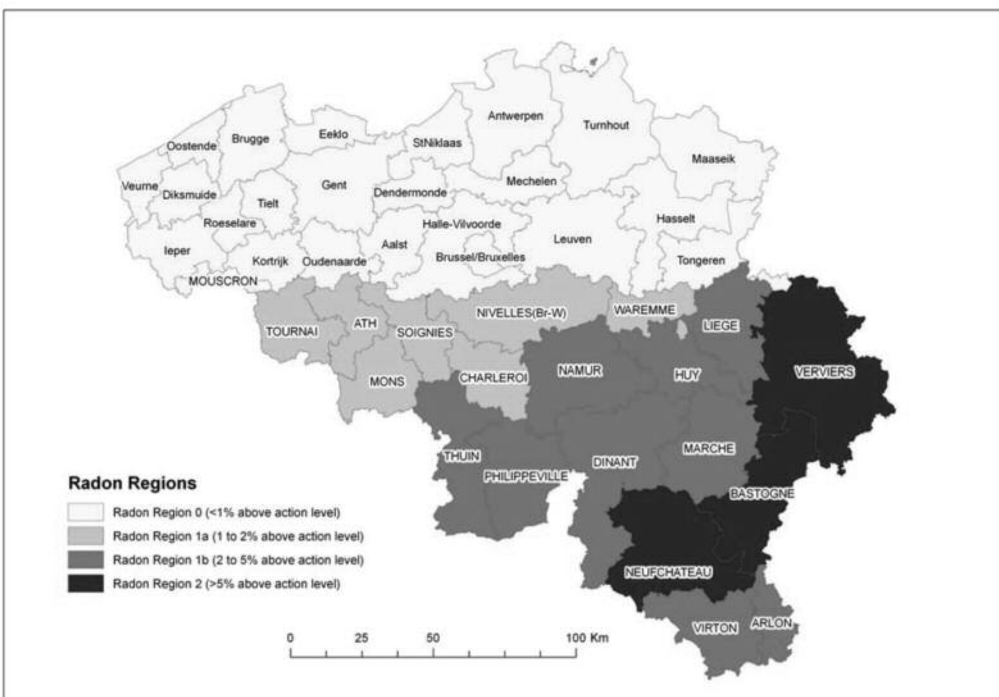


Fig. 1. Radon distribution per district.

**Table 1. Statistics for the indoor exposure of the Belgian population. GM: Geometric mean. GSD geometric standard deviation. Radon concentrations are in Bq/m³.**

| | Population | dwellings | Median | GM | GSD | Max | % >100 | % >200 | % >400 | % >800 |
|---|---|---|---|---|---|---|---|---|---|---|
| Belgium | 10584534 | 5043023 | 52 | 59 | 1.7 | 4204 | 11.0 | 2.2 | 0.4 | 0.1 |
| Wallonia | 3435879 | 1570265 | 69 | 84 | 2.0 | 4204 | 25.0 | 4.4 | 1.3 | 0.3 |
| Flanders | 6117440 | 2928158 | 38 | 44 | 1.2 | 70 | 5.0 | 0.8 | 0.0 | 0.0 |
| Brussels | 1031215 | 544601 | 38 | 44 | 1.2 | 120 | 5.0 | 0.8 | 0.0 | 0.0 |
| HRA | 376568 | 166000 | 127 | 137 | 2.5 | 5500 | 43.0 | 33.0 | 13.1 | 4.3 |

## Material and methods

The Belgian Cancer Registry containes LC incidence data on a municipal scale starting from the year 2004. The most recent data concern 2005. These data show the variability in LC incidence rate between men and women as well as some regional variation. Table 2 shows the annual LC incidence rate for the period 2004-2005 in Belgium. For this period, about 7000 LC per year have been registered.

**Table 2. Observed annual LC incidence rate in Belgium in the period 2004-2005.**

| Region | population | men | women | total |
|---|---|---|---|---|
| Belgium | 10584534 | 5361.5 | 1539.5 | 6901.0 |
| Wallonia | 3435879 | 1744.0 | 521.5 | 2265.5 |
| Flanders | 6117440 | 3213.5 | 844.0 | 4057.5 |
| Brussels | 1031215 | 404.0 | 174.0 | 578.0 |
| HRA | 376568 | 180.0 | 61.0 | 241.0 |

**Table 3. Observed annual LC incidence rate in the HRA in the period 2004-2005.**

| District | men | women | total |
|---|---|---|---|
| Verviers | 127.5 | 46.5 | 174.0 |
| Bastogne | 21.5 | 6.0 | 27.5 |
| Neufchâteau | 31.0 | 8.5 | 39.5 |
| **Total** | **180** | **61** | **241** |

The linear increase without threshold of the relative risk with indoor radon concentration has been estimated in various recent studies (Baysson et al., 2004; Darby et al., 2005). In this paper, the value of 16% increase of relative risk per trench of 100 Bq/m³ has been used following Darby et al., 2005. This leads to the estimation of LC incidence rate based on the average (GM) radon concentration for each region (Table 4). The obtained values show a good correlation between the observed values (table 2) and calculated LC occurrence. This estimation uses a smoker population of 1/3, which is justified taking into account the importance of the long term exposure of the population.

**Table 4. Estimated annual LC incidence rate in Belgium for smokers (S) and non-smokers (NS). Lifetime LC risk (0.16% increase per Bq/m³)* expressed per thousand. Lifetime =70 y.**

| | LC risk NS (promille) | LC risk S (Promille) | LC NS | LC S | total | Without radon | due to radon |
|---|---|---|---|---|---|---|---|
| Belgium | 4.487 | 110.534 | 452 | 5571 | 6023 | 5504 | 520 (9%) |
| Wallonia | 4.651 | 114.574 | 152 | 1875 | 2027 | 1787 | 240 (12%) |
| Flanders | 4.389 | 108.110 | 256 | 3149 | 3405 | 3181 | 224 (7%) |
| Brussels | 4.389 | 108.110 | 42 | 521 | 563 | 536 | 38 (7%) |
| HRA | 4.999 | 123.139 | 18 | 221 | 239 | 196 | 43 (18%) |
| No radon* | 4.100 | 101.000 | | | | | |

*After Darby et al.. 2005*

A more refined estimate of LC occurrence can be obtained taking into account the variability of the radon exposure within the HRA. This estimate gives a slightly higher LC incidence rate.

**Table 5. Estimated annual LC incidence rate in the HRA for smokers (S) and non-smokers (NS).**

| Exposed to (Bq/m³) | Ref used (Bq/m³) | Population in the HRA | annual LC | | | | |
|---|---|---|---|---|---|---|---|
| | | | NS | S | total | without radon | due to radon |
| >800 | 800 | 18828 | 2 | 20 | 22 | 10 | 12 (56%) |
| 400 to 800 | 400 | 30125 | 2 | 24 | 25 | 16 | 10 (39%) |
| 200 to 400 | 200 | 86611 | 4 | 54 | 59 | 45 | 14 (24%) |
| <200 | 100 | 241004 | 11 | 133 | 144 | 124 | 20 (14%) |
| **total** | | **376568** | **19** | **232** | **250** | **194** | **56 (23%)** |



## Results

The number of calculated LC (Table 4) corresponds well to the number of observed LC (Table 2). On the national level this would mean that about 8% of the LC incidence rate would be due to radon. whereas this incidence rate due to radon increases to 18% in the HRA. The calculated incidence rate within the HRA depends largely on the exposure class, where for the highest (lifetime) exposures of more then 800 Bq/m³ 56% of the LC incidence rate could be attributed to radon.

When looking at the scatter plot of lung cancer incidence rate and radon concentration per district, no statistical correlation can be observed. For the data per municipality, the LC incidence rates for the observed period are so low that no correlation whatsoever can be observed. When looking at the (age standardised) LC incidence rate among women, however, a vague trend can be observed (Fig. 2).

Figure 3 shows the age standardised LC incidence rate among women per district. This figure shows that the HRA contain some of the highest incidence rates in the country, except for one district (District *Marche*) with very low LC incidence rates.

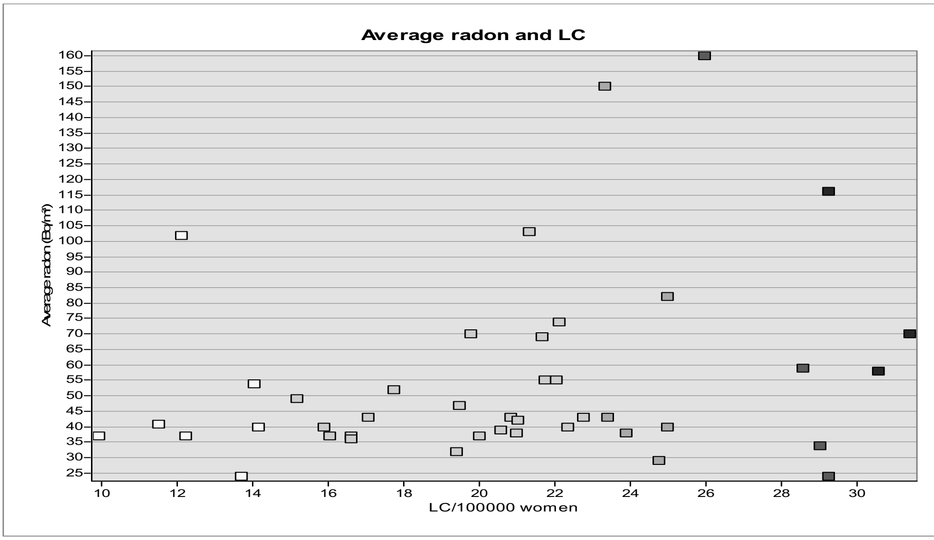


**Fig. 2. Scatter plot of the average (GM) radon concentration per district versus LC incidence rate among women.**

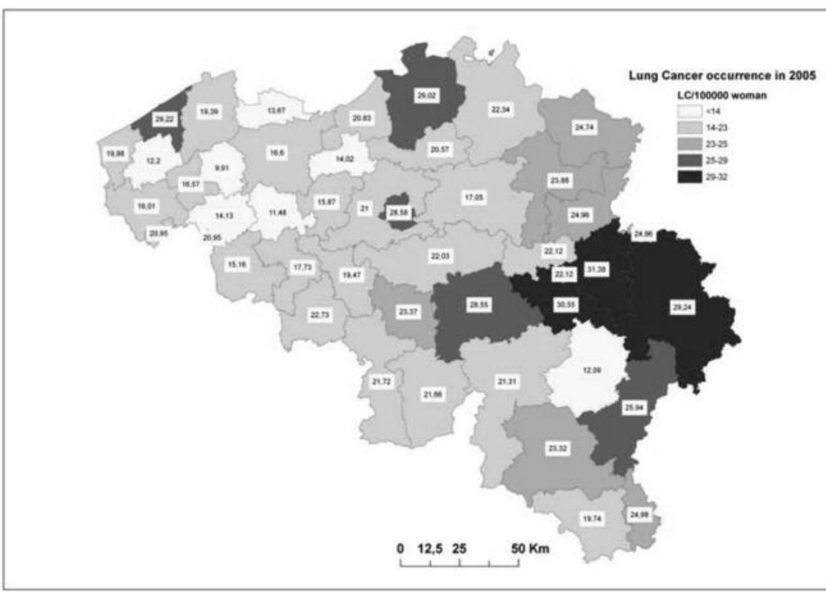


**Fig. 3. Distribution of age standardised LC incidence rate among women per district.**

Figure 4 shows the radon distribution per municipality on the Belgian territory. This figure shows that, in the case of the district 'Marche', partly covered by the HRA, only 4 municipalities, representing only 22% (12368) of the population of the total district (53123) actually are within the HRA.

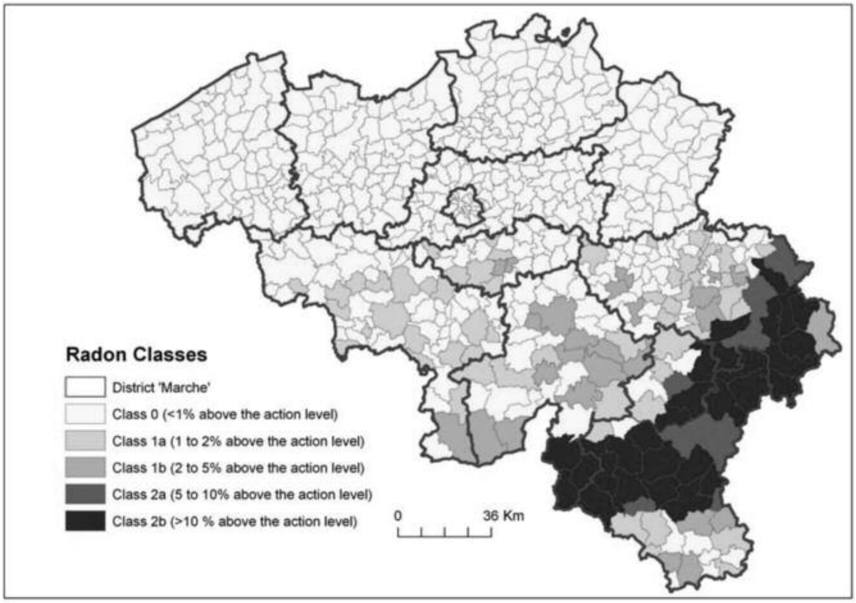


**Fig. 4. Radon distribution per municipality.**



## Discussion

The LC incidence for 2004-2005 contained in the National Cancer Registry correlates well with the data calculated from the radon risk studies. Comparing the observed number of lung cancers to the calculated number of lung cancers, there is a better match for the high risk areas then for the other areas. Part of the explanation could be that much more radon measurements have been made in the HRA than in the less affected regions. improving the accuracy of the calculated LC incidence values.

A slight trend can be observed when looking at the distribution of radon on the territory and LC incidence rate for women per district. A remarkable deviation from this general trend (district 'Marche' on fig. 4) could be due to the discrepancy between the district boundaries and the HRA limits. Refining the resolution of the LC incidence rate data to the municipality scale, however, leads to too few cases to allow statistical correlation. A possible trend in the LC incidence rate data among man, from the other hand, seems not at all suggested by the data. Smoking habits and occupational exposures might be a reason for this.

## Conclusions

A reoccurring question among the population in the high risk areas concerns the link between regional variations in LC incidence rate and increased indoor radon concentrations in their region. The current preliminary study investigates the risk estimates based on the recently published international epidemiological studies of radon and LC, applied to the high radon risk areas in Belgium, and compares them to the observed number of LC in this region as available from the Belgian Cancer Registry. Although the Belgian Cancer Register contains until today only data for the years 2004-2005, some preliminary conclusions can be drawn from the present analysis.

LC incidence rate correlates well with LC estimates taking into account radon, based on the most recent international epidemiological studies (Baysson et al., 2004; Darby et al., 2005). For areas with a better estimation of radon concentration distribution, the fit between the observed and calculated LC incidence rate is better. This confirms the quality of the used epidemiological studies and their ability to estimate the influence of radon on the general LC incidence rate and hence to allow a risk reduction policy based on the epidemiological findings.

This preliminary study indicates that the correlation between the regional variation of LC incidence and the regional variation in radon concentration is statistically weak and remains until now unproven. This is partly due to the very low number of cases, and due to the high uncertainty about other influencing factors, such as smoking/living habits and migration of inhabitants. Once the Cancer Registry data set will be extended and contain the LC incidence rate data of most recent years, a statistical study could possibly reveal this correlation, as is suggested by the weak trend already observed for LC incidence rate among women.



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# Accident dosimetry using Chip Cards : the belgian case

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# Determination and quantification of NORM radionuclides

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## Abstract

This paper discusses methodologies which can be used to identify naturally occurring radionuclides in substances using automatic spectrum analysis. The possibility to use automatic spectrum analysis in order to obtain an estimation of the activity concentration of the detected radionuclides is examined. The goal is to determine whether or not the activity concentration of a measured substance meets the regulation defined in the new upcoming European Basic Safety Standards with respect to naturally occurring radioactive materials (NORM). Existing techniques which are primarily used in lab settings are applied in industrial settings and tested. These techniques include artificial neural networks and automated spectrum analysis. The methodology is assessed and a comparison is made between NaI(Tl) and LaBr(Ce) based multi-channel analysers. The methodology is applied to several NORM materials with distinct activity concentrations: zirconium, ilmenite, bauxite, and fluorspar. In this way a methodology is constructed which can be applied in situ to allow determination and quantification of naturally occurring radionuclides.

## Introduction

Radionuclides of the natural radioactive series of uranium and thorium are present everywhere in the earth crust. Concentration of these nuclides is depending on the composition of the soil. Besides uranium and thorium nuclides, an amount of potassium-40 is also present. All these nuclides produce radiation doses to all human beings. In addition, industrial processes can lead to an accumulation of naturally occurring radioactive materials (NORM) due to operations in end-, by- or waste-products. The concentration of nuclides can be accumulated in such a way that radiation protection is necessary.

A uniform approach towards NORM by all European member states is a primary goal. The European Commission is therefore currently recasting Council Directives with respect to natural radiation sources (European Commission 2010). One of the new elements is the construction of a positive list of industrial activities in the non-nuclear sector that may be subject to notification. As already described in UNSCEAR 2000 and ICRP Publication 75 the acceptable dose rate threshold can be aligned with the activity concentration of materials. As a result the activity concentration will be used to determine whether regulatory authorities need a prior authorisation.

This means it is important to have a technique to determine the activity concentration of NORM. Since the activity concentration has to be measured in all the products, by-products and residues in an industrial process, a fast and usable methodology is mandatory. Nowadays the activity concentration is generally being measured by sample analysis which is a cumbersome, time and money consuming job.

In this work the objective is to construct a tool that can automatically decide in an industrial setting whether a measured substance complies with the new European Directive's activity concentration limits. This has to occur in known geometries by using a relatively cheap NaI(Tl) probe-based multichannel analyzer (MCA) connected to a tablet-PC. Custom software on the tablet steers the MCA to capture a spectrum and to interpret the spectrum straightaway. Based on the spectrum, the weight of the substance and its density, an estimation of the activity concentration is made and presented to the user.

To assess the technique proposed we captured several spectra of distinct NORM materials in a known geometry of a NORM handling company. The company stores and handles sugars, fertilizers, chemicals, minerals, iron, steel and wood products. The handling comprises bagging, repacking, sieving, sifting, weighing, mixing and conditioned storage in contamination-free warehouses. The accuracy of the tool was assessed by comparing the results with the results of an accepted method based on sample analysis.



In this work we focus on tool support. The objective is to construct a tool that can automatically decide in an industrial setting whether a measured substance complies with the new European Directive's activity concentration limits.

## Tool support for determination and quantification of NORM radionuclides in industrial settings

An important goal of our current research project is to make an inventory of the issues of NORM in a NORM handling company in collaboration with the Federal Agency of Nuclear Control.

The measurement tool was designed in such a way that at the end of the project the employees of the industry can use it independently. Therefore it has to be user-friendly and applicable in distinct industrial circumstances. Software is constructed that can be easily adapted according to the environmental context: several distinct geometries are present so that the end user can select the geometry that is applicable to the current context-of-use. For example: when the substance is contained in a shipping container, this geometry can be selected and subsequently parameters with respect to a shipping container (dimensions, probe location, container wall properties etc.) can be filled out by the user. On the other hand when the substance is contained in a bigbag (common used bag in industry containing dry bulk substances) this can be selected by the user and geometry properties can be filled out by the user accordingly (diameter, circumference, etc.).

As big bags were the most common geometry in this company, the tool was at first adjusted for this model (Fig. 1). Big bags contain dry bulk substances with a mass typically between 1 and 2 ton. Activity concentrations of nuclides in big bags were determined on the side but also on the top of the bag. The measurements on the top correspond the most to the sample analysis.

In practice, the bags were placed outside the warehouse to avoid interference with radiation caused by other bags. Geometry of the bag was determined (height, net mass, perimeter, volume). Two probes (NaI(Tl) and LaBr(Ce)) were set on the top and in contact with the bags and were connected with the spectrometer and software. Measurements were repeated 10 times for 15 minutes in order to control the reproducibility of measurements. A spectrum was automatically generated and analysed.

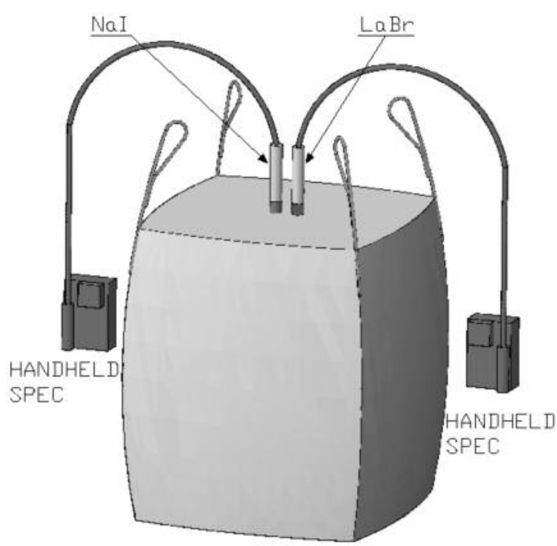


**Fig. 1. A bigbag with two multi-channel analysers (NaI(Tl) and LaBr(Ce)) recording a spectrum of a known substance.**

In the following sections two techniques are discussed which can be applied to identify NORM radionuclides by using Artificial Neural Networks and to quantify the activity concentration of NORM radionuclides by applying energy calibration by modelling the measured container. Both techniques make use of automated spectrum analysis of the spectra recorded in the industrial setting of the NORM handling company. The accuracy of the tool was checked by comparison of the analyses with sample analysis.

## Determination of nuclides with Artificial Neural Networks (ANN)

This section elaborates on a technique to classify NORM radionuclides using artificial neural networks. The following section will discuss a technique to estimate the activity concentration.

### Artificial Neural Networks for gamma-ray spectrum analysis

Artificial Neural Networks ANN simulate biological neural networks in a computational model that can be implemented in a software system. ANN already have a long history of applications in physics and chemistry in general and in nuclear science in particular with proven successful results on spectrum analysis (Long 1997) (Keller et al. 1994) (Yoshida et al. 2002) (Saritha et al. 2009). A key characteristic of ANN is the excellent performance on coping with data containing noise. Milford identified the generalization ability of ANN as the reason for this performance when increasing amounts of Gaussian noise were added to spectra (Milford 2002). Saritha et al. And Keller et al. compared a neural network to an Optimal Linear Associative Memory (OLAM) for the classification of linearly separable data (Saritha et al. 2009) and (Keller et al. 1994). While OLAM was superior to a neural network when Monte Carlo generated spectra were used, the ANN was again found to be the best solution for noisy data.

### Practical Approach



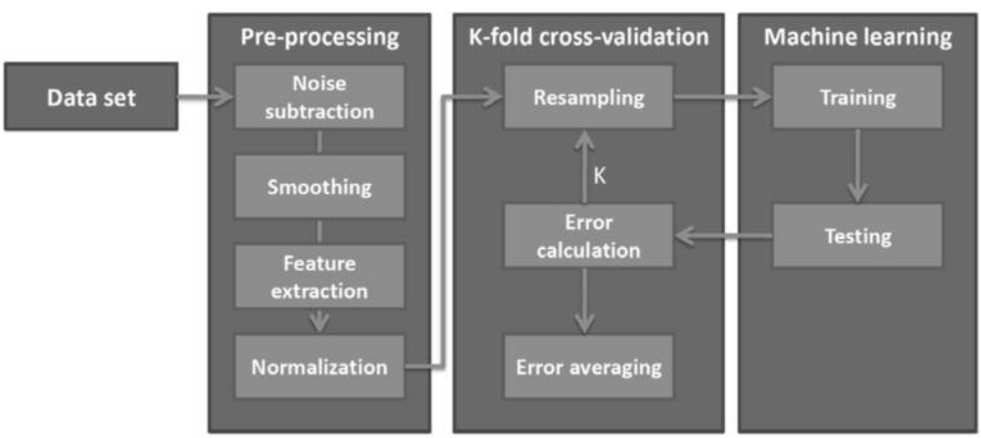


**Fig. 2. Schematic overview of the machine learning sequence.**

Figure 2 presents a schematic overview of the machine learning sequence of the ANN that has been implemented. The input data set is a collection of raw spectra obtained by the measurements in the industrial case study. The machine learning sequence consists of three steps: pre-processing, cross-validation, and machine learning.

Before the spectral data can be fed to the ANN a pre-processing step is applied to extract the most relevant data from the spectrum. Although this is strictly not necessary since the ANN can learn which data are irrelevant. Feeding 512 to 4096 channels used by an MCA to the ANN would be inefficient and decrease the training speed. Using trial and error the following pre-processing techniques generated the best results on the spectra recorded in the industrial case study: noise subtraction, running-average smoothing, peak-extraction based on Milford, and normalization (Milford 2002). The peak extraction algorithm investigates a specific number of channels surrounding a point to determine whether the point is a local maximum and thus a peak. This reduces the complexity of the input layer.

Figure 3 presents the implemented ANN. The ANN is a fully interconnected feed-forward network with one hidden layer. Back-propagation learning is used to train the ANN. Because of the pre-processing step, the number of input neurons is reduced to twelve, i.e. the respective position and height of six key peaks that can identify the presence of a radionuclide in the spectrum. The number of neurons in the hidden layer has to be chosen carefully in order to find a balance between the model's complexity and the generalization capacity of the ANN.

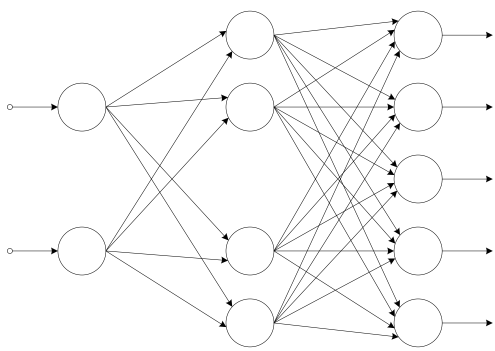

**Fig. 3. Model of the implemented ANN.**

To validate the ANN k-fold cross-validation was applied with k=10. This means the input data set was divided in ten equal collections of spectra from which nine are used to train the ANN and the remaining one is used for validation. Afterwards the error is calculated and the input data set is resampled for another run. This is repeated until the cross-validation error < 1%.

## Results

The gamma spectra are recorded using a NaI(Tl) and LaBr(Ce) detector in the industrial environment. A training set of eighty spectral samples was used that represented all detectable isotopes (K-40, Ra-226, Th-232, U-235, and U-238) in equal numbers. The k-fold cross-validation was applied to exploit the reasonably small data set of eighty samples. A series of ten repeated 10-fold cross-validations were used to verify the performance of the ANN.

In order to optimize the performance of the network, the following parameters were isolated and compared by their accuracy, mean-squared error (MSE) and mean-absolute error (MAE):

- Momentum: scaling factor to specify to what degree the weights of the neurons change from the previous step of the learning algorithm. The momentum appeared to be acceptable with respect to the accuracy and the MSE between 0.1 and 0.3.

- Hidden-layer size: the MSE and MAE both reach a minimum when the hidden layer consists of four neurons.

Furthermore the learning rate and the number of epochs (iterations of an entire training set) were taken into account.
The results showed that the ANN classified the spectra with an accuracy of 85% on average which corresponds to an error rate of 15%. This large error was due to the problems that the ANN had with the classification of U-238. The best performance of the ANN on U-238 was 87%. The other isotopes (K-40, Ra-226, Th-232, and U-235) were classified with an accuracy of 100%.

## Quantification of NORM radionuclides

In earlier work we discussed how the activity concentration of NORM radionuclides was quantified using a NaI(Tl)-based multi-channel analyser (MCA) using spectrum analyses on spectra captured in an industrial setting (Pellens et al. 2010). In this section we will compare results of spectrum analysis captured by an MCA equipped with a NaI(Tl) probe with spectra from the same substances captured in the same environmental circumstances but with an MCA equipped with a LaBr(Ce) probe. Furthermore the technique is assessed by comparing these results to the results of sample analysis performed by a certified institution.

### Practical approach



The approach consists of automated spectrum analyses performed by customized software. Four substances known as NORM were measured in bigbags containing between 1000 kg and 2000 kg. The software was adapted to cope with spectra recorded by either NaI(Tl) and LaBr(Ce) probes. The final output of the software was an estimation of the activity concentration of NORM-radionuclides present in the measured substance. Measurements taken with NaI(Tl) and LaBr(Ce) are compared to results from sample analyses taken from the respective bigbags. The analyses on 250 g samples were performed by a certified lab. In the next section this comparison will be discussed.

The automated spectrum analysis was applied to ten spectra recorded on each substance. The same automated analysis algorithm was applied to the distinct substances.

Up to now, four distinct substances were considered: zirconium, ilmenite, bauxite, and fluorspar. The substances were chosen in a way that there was a variety in the respective activity concentration of the radionuclides present.

### Results

The results are presented in three tables. Each table presents the results of one NORM radionuclide by comparing the automated spectrum analysis of spectra recorded with the two types of probes (Na(Tl) and LaBr(Ce)), the sample analysis by the certified lab and the recommendation as described in the reviewed basic safety standards by the European Commission. The results are presented for each of the four substances considered in this research.

**Table 1. Comparison of spectral analysis results of 900s measurements using a NaI(Tl) and LaBr(Ce) probe with results of a certified lab for the Th-232 radionuclide.**

| Substance | NaI(Tl) | | LaBr(Ce) | | Certified lab SA | EC BSS |
|---|---|---|---|---|---|---|
| | Act Conc ($Bq \cdot g^{-1}$) | Rel. Error (%) | Act Conc ($Bq \cdot g^{-1}$) | Rel. Error (%) | Act Conc ($Bq \cdot g^{-1}$) | |
| Zirconium | 0.53 | 6 | 0.52 | 5 | 0.50 | |
| Ilmenite | 0.28 | -16 | 0.36 | 6 | 0.34 | |
| Bauxite | 0.29 | -2 | 0.33 | 12 | 0.30 | |
| Fluorspar | <MDA = 0.03 | | 0.08 | | <MDA = 0.02 | |

Table 1 presents the results of the Th-232 radionuclide. The sample analysis shows that the performance of the automated sample analysis of the zirconium spectra are nearly the same for the two different probes. There is an overestimation of 5% to 6% in comparison to the certified sample analysis. The activity concentration of Th-232 in ilmenite is performed way better with the LaBr(Ce) probe (6% overestimation) in comparison to the NaI(Tl) (underestimation of 16%). The automated analysis of bauxite presents a different picture: the analysis of the NaI(Tl) probe delivers a better result. Finally the activity concentration of fluorspar does not exceed the minimum detectable activity (MDA) for the NaI(Tl) analysis and the sample analysis. We can conclude that the automated spectrum analysis for the LaBr(Ce) probe delivers an overestimation of the activity concentration of Th-232 in comparison to the NaI(Tl) and sample analysis results. This introduces a more safe result than the NaI(Tl) which may deliver an underestimation. The last column of the table compares the results with the revised basic safety standards. None of the substances exceeds the limit of 1 $Bq \cdot g^{-1}$ for the Th-232 series.



**Table 2. Comparison of spectral analysis results of 900s measurements using a NaI(Tl) and LaBr(Ce) probe with results of a certified lab for the U-238 radionuclide.**

| Substance | NaI(Tl) | | LaBr(Ce) | | Certified lab SA | EC BSS |
|---|---|---|---|---|---|---|
| | Act Conc ($Bq \cdot g^{-1}$) | Rel. Error (%) | Act Conc ($Bq \cdot g^{-1}$) | Rel. Error (%) | Act Conc ($Bq \cdot g^{-1}$) | |
| Zirconium | 1.79 | -8 | 2.13 | 9 | 1.94 | |
| Ilmenite | 0.09 | | <MDA = 0.053 | | <MDA = 0.31 | |
| Bauxite | <MDA = 0.05 | | 0.25 | | <MDA = 0.58 | |
| Fluorspar | 0.08 | | 0.19 | | <MDA = 0.40 | |

Table 2 summarizes the results of the same analyses for the U-238 radionuclide. According to the sample analysis results of the certified lab, only zirconium exceeds the minimum detectable activity. The activity concentration delivered by the automated spectrum analysis of the NaI(Tl) and LaBr(Ce) spectra are comparable: an underestimation of 8% is produced by the NaI(Tl) and an overestimation of 9% by the LaBr(Ce). The activity concentration exceeds the limit of 1 $Bq \cdot g^{-1}$ for the U-238 series.

**Table 3. Comparison of spectral analysis results of 900s measurements using a NaI(Tl) and LaBr(Ce) probe with results of a certified lab for the Ra-226 radionuclide.**

| Substance | NaI(Tl) | | LaBr(Ce) | | Certified lab SA | EC BSS |
|---|---|---|---|---|---|---|
| | Act Conc ($Bq{\cdot}g^{-1}$) | Rel. Error (%) | Act Conc ($Bq{\cdot}g^{-1}$) | Rel. Error (%) | Act Conc ($Bq{\cdot}g^{-1}$) | |
| Zirconium | 1.8 | -15 | 2.1 | -2 | 2.14 | |
| Ilmenite | <MDA = 0.04 | | <MDA = 0.053 | | 0.04 | |
| Bauxite | 0.27 | -8 | 0.27 | -9 | 0.30 | |
| Fluorspar | 0.11 | -37 | 0.19 | 7 | 0.18 | |

Finally table 3 presents the results of the analysis of the Ra-226 radionuclide. For the substances zirconium and fluorspar the LaBr(Ce) outperforms the NaI(Tl): a respective underestimation of 2% and overestimation of 7% versus an underestimation of 15% and 37% for the Ra-226 activity concentration. The results of the spectrum analysis for bauxite are comparable. Again, the only exceeding activity concentration in comparison to the basic safety standards requirements is detected for zirconium.

### Discussion

Looking at the results presented in the previous section, a conclusion can be made that the LaBr(Ce) performs better than the NaI(Tl) when automated spectrum analysis is applied en builds assurance because the error is mostly an overestimation. The results are significantly better when Ra-226 has to be quantified. The comparison of the performance on U-238 is about the same, but only zirconium exceeded the minimum detectable activity. The results of the Th-232 analyses show distinct performances in comparison to the certified sample analysis.



An important issue in the automated spectral analysis seemed to be the detection and quantification of U-238. The certified method using sample analysis could not deliver a justifiable quantification of the activity concentration for three of the four substances. The automated spectral analysis method delivered an estimation of the activity concentration below the minimum detectable activity of the certified lab. Using the automated spectrum analysis the proposed method is able to quantify the activity concentration accurately enough to determine whether the activity concentration is below or above the threshold used in the new European basic safety standards. Further research is required to narrow down the limitations of this methodology to determine when a more accurate analysis is necessary, i.e. when the activity concentration approximates the basic safety standards' limits.

## Conclusions

Automated spectrum analysis was applied on spectra recorded in an industrial setting. The main objective was to study whether automated spectrum analysis can be used in providing a fast tool to check the applicability of the new European basic safety standards with respect to NORM material. A methodology has been constructed consisting of a tablet-PC running a software that steers a measurement and interprets the spectrum accordingly to approximate the activity concentration of the measured substance.

Both machine learning techniques and traditional automated spectrum analysis were studied in order to determine and quantify NORM radionuclides. Spectra were recorded with two different probes (NaI(Tl) and LaBr(Ce)). Results showed a better performance of the analyses with a LaBr(Ce) probe. In this paper, we showed one can use an ANN to determine the presence of K-40, Ra-226, Th-232 and U-235 with an accuracy of 100% while the determination of the presence of U-238 is 87%. It is in our intention to use these figures to optimize the quantification algorithms used in the automatic spectral analysis.

Results of analyses of four investigated NORM materials were compared with the Council Directives (whether the measured values were in the safe zone, around the threshold, or above the threshold). The four substances which were the subject of this study were accurately classified according to the basic safety standards taking the relative error into account.

Further optimization of the tool will be an important objective of this project. The tool will be able to tell in a very short period if a company needs notification according to the new European basic safety standards.

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The European Commission is currently in the process of recasting five Council Directives: Basic Safety Standards Directive (96/29/Euratom), Medical Directive (97/43/Euratom), Directive on High Activity Sealed Sources (2003/122/Euratom), Directive on Outside Workers (90/641/Euratom), Directive on Public Information (89/618/Euratom). 2010.

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# ENETRAP-II: development of European training schemes for RPE's and RPO's

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## Abstract

ENETRAP II, aims at developing reference standards and good practices for education and training programmes for radiation protection experts and officers, reflecting the needs of these professionals in all sectors where ionising radiation is applied. The introduction of a radiation protection training passport as a mean to facilitate efficient and transparent European mutual recognition of these professionals is another ultimate deliverable of this project. It is envisaged that the outcome of ENETRAP II will be instrumental for the cooperation between regulators, training providers and customers (nuclear industry, research, non-nuclear industry, etc.) in reaching harmonisation of the requirements for, and the education and training of, radiation protection experts and officers within Europe, and will stimulate building competence and career development in radiation protection to meet the demands of the future.

## Introduction

Radiation protection (RP) is a major challenge in the industrial applications of ionising radiation, both nuclear and non-nuclear, as well as in other areas such as the medical and research area. As is the case with all nuclear expertise, there is a trend of a decreasing number of experts in radiation protection due to various reasons. On the other hand, current activities in the nuclear domain are expanding: the nuclear industry faces a so-called "renaissance", high-tech medical examinations based on ionising radiation are increasingly used, and research and non-nuclear industry also make use of a vast number of applications of radioactivity.

Within this perspective, maintaining a high level of competency in RP is crucial to ensure future safe use of ionising radiation and the development of new technologies in a safe way. Moreover, the perceived growth in the different application fields requires a high-level of understanding of radiation protection in order to protect workers, the public and the environment of the potential risks. A sustainable education and training (E&T) infrastructure for RP is an essential component to combat the decline in expertise and to ensure the availability of a high level of radiation protection knowledge which can meet the future demands.

Today's challenge involves measures to make the work in radiation protection more attractive for young people and to provide attractive career opportunities, and the support of young students and professionals in their need to gain and maintain high level RP knowledge. This can be reached by the development and implementation of a high-quality European standard for initial education and continuous professional development for radiation protection experts (RPEs) and radiation protection officers (RPOs), and a methodology for mutual recognition of these professionals on the basis of available EU instruments, such as the European qualification framework (EQF) and/or the directive 2005/36/EC.



Within the framework of this project, the RPE and RPO should be interpreted as:
**Radiation protection expert** (RPE): *an individual having the knowledge, training and experience needed to give radiation protection advice in order to ensure effective protection of individuals, whose capacity to act is recognized by the competent authorities.*
**Radiation protection officer** (RPO): *an individual technically competent in radiation protection matters relevant for a given type of practice who is designated by the undertaking to oversee the implementation of the radiation protection arrangements of the undertaking*.
These are the definitions proposed by ENETRAP 6FP (www.sckcen.be/enetrap) and EUTERP (www.euterp.eu) to the EC DG TREN and Article 31 group, who is working on the revision of the Basic Safety Standards.

## Project details

Determined to build further on the achievements of 6 FP ENETRAP, most ENETRAP partners participate in 7FP ENETRAP II (www.sckcen.be/enetrap2). The overall objective of this project is to develop and implement European high-quality "reference standards" and good practices for E&T in RP, specifically with respect to the RPE and the RPO. These "standards" will reflect the needs of the RPE and the RPO in all sectors where ionising radiation is applied (nuclear industry, medical sector, research, non-nuclear industry). The introduction of a radiation protection training passport as a mean to facilitate efficient and transparent European mutual recognition is another ultimate deliverable of this project.

With respect to the RPE the overall objective is to be achieved by addressing both education and training requirements.
In the field of education this project deals with high-level initial programmes, mainly followed by students and/or young professionals. It is foreseen to analyse the European Master in Radiation Protection course, which started in September 2008. Broadening of the consortium and quality analysis of the providers and the content of the modules can be performed according to, primarily, the standards and guidelines for quality assurance in the European higher education area (ENQA) and, secondly, to the ENEN standards.
In the field of RPE training the ultimate goal is the development of a European mutual recognition system for RPEs. Hereto, the ENETRAP training scheme initiated as part of the ENETRAP 6FP will be used as a basis for the development of a European radiation protection training scheme (ERPTS), which includes all the necessary requirements for a competent RPE. In addition, mechanisms will be established for the evaluation of training courses and training providers.
With respect to the RPO role the desired end-point is an agreed standard for radiation protection training that is recognised across Europe. Data and information obtained from the ENETRAP 6FP will be used to develop the reference standard for radiation protection training necessary to support the effective and competent undertaking of the role.

Furthermore, attention is given to encouragement of young, early-stage researchers. In order to meet future needs, it is necessary to attract more young people by awaking their interest in radiation applications and radiation protection already during their schooldays and later on during their out-of-school education (university or vocational education and training). Radiation protection experts and officers work more and more on a European level. It is therefore important bringing together all the national initiatives at a European level: tomorrow’s leaders must have an international perspective and must know their colleagues in other countries.



It is envisaged that the outcome of ENETRAP II will be instrumental for the cooperation between regulators, training providers and customers (nuclear industry, medical sector, research and non-nuclear industry) in reaching harmonisation of the requirements for, and the education and training of RPEs and RPOs within Europe, and will stimulate building competence and career development in radiation protection to meet the demands of the future.

Specific objectives of the ENETRAP II project are to:
- develop the European radiation protection training scheme (ERPTS) for RPE training;
- develop a European reference standard for RPO training;
- develop and apply a mechanism for the evaluation of training material, courses and providers;
- establish a recognised and sustainable ERPTS "quality label" for training events;
- create a database of training events and training providers (including OJT) conforming to the agreed ERPTS;

- bring together national initiatives to attract early-stage radiation protection researchers on a European level;
- develop some course material examples, including modern tools such as e-learning;
- develop a system for monitoring the effectiveness of the ERPTS;
- organise pilot sessions of specific modules of the ERPTS and monitor the effectiveness according to the developed system;
- development of a European passport for CPD in RP.

The objectives of ENETRAP II 7FP will be reached by several activities dealing with

- the analysis of job requirements (RPE and RPO);
- the design and implementation of appropriate training standards and schemes to support these requirements;
- development and application of a quality assurance mechanism for the evaluation of the training events, used material and training providers;
- setting up a database of training events and providers conforming to the agreed standards;
- the development of training material (traditional texts, as well as the introduction of more modern tools such as e-learning modules) that can be used as example training material;
- monitoring the effectiveness of the proposed training schemes.



The final goal is the development of a European mutual recognition system for RPEs and the introduction of a training passport.

The different work packages (WP) defined in this project are:

| | |
|---|---|
| WP1 | Co-ordination of the project |
| WP2 | Define requirements and methodology for recognition of RPEs |
| WP3 | Define requirements for RPO competencies and establish guidance for appropriate RPO training |
| WP4 | Establish the reference standard for RPE training |
| WP5 | Development and apply mechanisms for the evaluation of training material, events and providers |
| WP6 | Create a database of training events and training providers (including OJT) conforming to the agreed standard |
| WP7 | Develop of some course material examples (text book, e-learning modules, …) |
| WP8 | Organise pilot sessions, test proposed methodologies and monitor the training scheme effectiveness |
| WP9 | Introduction of the training passport and mutual recognition system of RPEs |
| WP10 | Collaboration for building new innovative generations of specialists in radiation protection |

ENETRAP II 7FP is realised by 12 partners, each having relevant experience in policy support regarding E&T projects on radiation protection. It concerns SCK•CEN (Belgium), CEA-INSTN (France), Karlsruhe Institute of Technology, Centre for Advanced Technological and Environmental Training KIT-FTU (Germany), Federal Office for Radiation Protection BfS (Germany), the Italian National Agency for New Technology, Energy and Environment ENEA (Italy), NRG (The Netherlands), CIEMAT (Spain), Health Protection Agency HPA (UK), the ENEN Association (France), the Nuclear and Technological Institute ITN (Portugal), the Budapest University of Technology and Economics BME (Hungary), and University Politehnica of Bucharest (Romania). Staff members of the different partners who play a key role in this project, have also proven to be highly involved with E&T matters, on national and international levels, and are member of several E&T networks. Most of them also have an advisory role towards the national regulatory authority.

ENETRAP II (grant agreement number 232620) is a coordination action that runs under the theme "Euratom Fission Training Schemes (EFTS) in all areas of Nuclear Fission and Radiation Protection" (Fission-2008-5.1.1). The project will run over 36 months.

## Results

Although this project is still in its first phase, some work packages have already reached intermediate results. In the following paragraphs a summary is given of the work carried out in the different WPs, and the first achievements are highlighted.



### Requirements and methodology for recognition of RPEs

WP2 deals with the requirements for recognition of RPEs and the development of a methodology for the recognition of RPEs. Although the execution of any recognition process is the responsibility of the national regulatory authority, ENETRAP II will put forward a harmonised methodology, in line with the national approaches. The existence of this European methodology will facilitate the ultimate goal: a European mutual recognition process for RPEs. Qualification, competence, and continuous professional development will be discussed and elements for these three requirements will be defined. An outline of the proposals for key elements of a national scheme for RPE recognition was put forward at the most recent ETRAP conference (Lisbon, November 2009 (http://www.euronuclear.org/events/etrap/index.htm). Here, also a questionnaire was presented which was sent out to all participants, EUTERP contact points and other relevant stakeholders. The results of the questionnaire are currently being analysed and will be used to provide guidance with respect to national schemes for recognition of RPEs. From there, a mechanism will be developed for the mutual recognition of RPEs between Member States.

### Requirements for RPO competencies and establishment of guidance for appropriate RPO training

WP3 deals with requirements for RPO competencies and the establishment of guidance for appropriate RPO training. Employees, appointed to act as RPOs in hospitals, industrial companies or teaching and research institutions should have an adequate level of understanding of concepts related to radiation protection and understand the radiation protection issues pertinent to their radiation application. Therefore the level and format of training required by an RPO is dependant on the complexity of that application. It is therefore essential, on the EU level, (i) to define requirements for the competencies of RPOs according to their area of work and specific radiation protection tasks, and (ii) to establish European reference standards for RPO training. The first intermediate report on this topic is submitted.

#### Establishment of the reference standard for RPE training

WP4 continues on the achievements of WP2. Here, it is the aim to develop appropriate European radiation protection training schemes (ERPTS), with objectives, target audience(s), audience prerequisites, required topics, suggested durations and evaluation methods for both initial and refresher training of RPEs, taking into account the nature and requirements of the RPE role. The starting point is the ENETRAP 6FP training scheme. Furthermore internationally recognised training material such as the material developed by the IAEA will be incorporated. The ERPTS should meet the requirements of the revised definitions of the RPE and should eventually replace Communication 98/C133/03, as a guide for the Member States to develop, or evaluate, their national strategies for RPE qualification and recognition.

#### Development and application of mechanisms for the evaluation of training material, events and providers



In the EU, a vast number of training events, material and providers exist. Given that formal recognition is required for RPEs, it would be prudent for training providers involved in the RPE training process to also be formally recognised. The aim of this WP5 is to develop a mechanism for the comparison, through a transparent and objective methodology, of training materials, courses and training providers, which can be used by regulatory authorities to evaluate their national radiation protection training programme for compliance with the ERPTS. First results are presented at this conference.

#### Database of training events and training providers

It is foreseen in WP6 to create a database of training event and providers conform to the agreed standards. The database will be made public through the ENETRAP II website and will thus be available for all interested parties. It is the aim that such a move would add credibility to the recognition process and would help to provide reassurance to RPE candidates and to employers that the training obtained satisfies an agreed European standard. It is foreseen that this database will also incorporate an overview of institutes hosting on-the-job-training possibilities. First announcements are foreseen by the end of 2010.

#### Development of course material

In order to provide examples of standardised training material, meeting the requirements of the ERPTS, WP7 foresees a European textbook for several modules of the ERPTS. It is suggested to launch a "cyber book", using the MOODLE platform that was introduced in ENETRAP 6FP. The modules that will be treated in this book are to be decided from the 66 entries WP7 received to their survey amongst the partners regarding the available course material. An additional suggestion is to create a sonorized (video + audio) PowerPoint presentation.

#### Pilot sessions

In the framework of ENETRAP II, pilot sessions of the European reference training scheme will be organised. The date put forward for the first pilot session, containing the basic RP modules and a specialized module on radiation protection issues in nuclear power plants, is spring 2011. This will be organised at KIT-FTU, Germany. Another specialized module on NORM issues will be organised at HPA, UK. At this conference the pilot sessions are presented in a poster presentation.

#### Introduction of a training passport and mutual recognition system

The ultimate goal of the ENETRAP II project is the introduction of an EU mutual recognition system for RPEs. In WP9 coordinating actions will be undertaken to establish such a system. Furthermore, the European training passport will be introduced as a tool for facilitating an efficient and transparent mutual recognition system.
Whenever possible, a collaboration will be established with the "training" working groups of the three EU "platforms" that were launched in 2007 (in particular, to discuss the added value of a "European training / skills passport" and the balance between theoretical and practical training that is desired to improve both the quality and the mobility of nuclear experts in public as well as private sector). The results of this WP are expected in the last phase of the project.



#### Building new innovative generations of specialists in radiation protection

Those people who developed concepts in radiation protection and held leadership positions at universities and research institutions to further develop radiation research and educate and train the next generation in the EU are retired or starting to retire. We are facing the same situation for numerous radiation protection experts and officers who devoted their knowledge and experience to build up a high level of radiation safety in all radiation applications in industry, medicine and research in the EU. In order to maintain this high level and to further develop a European safety culture, it is necessary to attract more young people by awaking their interest in radiation applications and radiation protection. More young people must be inspired to take an interest in radiation research and prepared to take leadership positions at universities and radiation applications in industry, medicine and research in the EU. Because high-level RP professionals often work in a European context, tomorrow’s leaders will benefit from having an international perspective and knowing their colleagues in other countries.

### Summary and conclusions

Based on the outcome of the ENETRAP 6FP, ENETRAP II 7 FP aims at contributing further to the EU harmonisation of E&T of radiation protection professionals. With the introduction of a modular European reference training scheme and European recognition methodologies, key issues will be delivered for the development and implementation of mutual recognition system of RPEs. In this way ENETRAP II meets the EC requirements to rely on the principles of modularity of courses and common qualification criteria, a common mutual recognition system, and the facilitation of teacher, student and worker mobility across the EU. ENETRAP II will structure research on radiation protection training capacity in all sectors where ionising radiation is applied. End users and specifically regulatory authorities are represented through foreseen participation in the advisory board which will advise about the best balance between supply and needs, thereby ensuring stable feed back mechanisms. The tasks defined in this project maximise the transfer of high-level radiation protection knowledge and technology, addressing young as well as experienced radiation protection workers. In this context, the proposed project will thus contribute to meeting the objectives of the EURATOM research and training work programme.

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# Radiation protection education and training activities at the Belgian Nuclear Research Centre SCK•CEN

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## Abstract
The scientific world of radiological protection (RP) is in constant motion, triggered by new research as well as by developments and events in the daily industrial and medical sectors. In addition, national and international regulatory policies try to streamline and guide daily practice along procedures that guarantee the protection of workers and public, and that at the same time also ensure optimization of all peaceful uses of applications of radioactivity. Harmonization and coordination are in this sense of the utmost importance, not only 'on the work floor', but also with regard to education and training (E&T). Within this spirit, the international school for Radiological Protection (isRP) of the Belgian Nuclear Research Centre SCK•CEN participates to several E&T activities: SCK•CEN experts lecture several courses within existing academic programs, and give guidance to Master and PhD students in the framework of their thesis. We also organize courses on a wide variety of RP topics for professionals of the nuclear and medical sector and - in parallel - we aim to play a role in national and international policy through active participation in several European networks.



## Introduction
The Belgian Nuclear Research Centre SCK•CEN was created in 1952 in order to give the Belgian academic and industrial world access to the worldwide development of nuclear energy. It is a Foundation of Public Utility, with a legal status according to private law, under the tutorial of the Belgian Federal Minister in charge of energy. Since 1991, the statutory mission gives priority to research on issues of societal concern such as safety of nuclear installations, radiation protection, safe treatment and disposal of radioactive waste, fight against uncontrolled proliferation of fissile materials and fight against terrorism. The Centre also develops, gathers and disseminates the necessary knowledge through education and communication, and provides all services asked for in the nuclear domain (by the medical sector, the nuclear industry and the government). Today, about 630 employees advance the peaceful industrial and medical applications of nuclear energy, and realize a turn-over of about 85 M EURO.

Thanks to its thorough experience in the field of peaceful applications of nuclear science and technology, the Belgian Nuclear Research Centre SCK•CEN has garnered a reputation as an outstanding centre of not only research, but also education and training. SCK•CEN is an important partner for training projects in Belgium (to the nuclear sector, the medical and non-nuclear sector), as well as at the international level (IAEA, EC, …). The Centre's know-how and infrastructure are available for education and training purposes. One of the research topics that is strongly developed at SCK•CEN's Institute for Environment, Health and Safety, is radiation protection. From years of experience and recent knowledge that results from the latest innovative research, an extensive range of course modules has grown. Our courses are directed to the nuclear industry, the medical and the non-nuclear industry, national and international policy organizations, the academic world and the general public.

## Academic collaborations

SCK•CEN experts are involved as lecturer in several academic programs, at Belgian and foreign universities and technical universities. They also deliver contributions to courses set up on specific occasions such as the courses given in the framework of ENEN, CHERNE, WNU, etc.

### Radiation Protection Expert



Together with XIOS Hogeschool Limburg, ISIB and IRE, SCK•CEN organizes the Radiation Protection Expert course, given in Dutch and in French. This course broadens the scientific and technological basic knowledge of radiological and nuclear techniques with special attention for practical radiation protection. It is aimed at professionals working with ionizing radiation, in all sectors. The program is in line with the legal requirements of the Belgian Royal Decree of July 20 2001, mentioning the prerequisites for accreditation as Radiation Protection Expert by the Belgian Federal Agency for Nuclear Control. SCK•CEN collaborators contribute to the Dutch course, for 96 of the total 120 hours.

### Guidance of PhD students

In a conscious desire to increase its pool of highly specialized young researchers and to tighten the links with the universities, SCK•CEN embarked in 1992 on a program to support PhD candidates and post-doctoral researchers. Since 1992, about 100 students started a PhD in collaboration with SCK•CEN and more than 50 post-docs joined our Centre. Today, about 35 young scientific researchers perform their work in research fields that reflect the priority programs and R&D topics of SCK•CEN, about half of them are working within the field of radiation protection.
Next to this, SCK•CEN experts also work with Master students, and even high school students (sixth year) have the opportunity to use our laboratories and other infrastructures in order to perform scientific experiments to support there thesis work.

## Training courses for professionals

Training courses of the international school for Radiological Protection of SCK•CEN cover a very broad offer. Different modules are foreseen as a "standard", but in principle all our courses are tailored to the specific needs, field of operation, and level of the trainees.

### Basic modules

The course series *Background and Basic Knowledge* collects general and more specific technical courses on radiological protection. The series consists of seven modules and provides the theoretical and practical knowledge required for implementing technical aspects of radiological protection in a medical or industrial working environment, both in the daily practice and in the management in the long term:

- Basic principles of nuclear physics
- Interaction of radiation with matter
- Radiation and dose measurements
- Biological effects of ionizing radiation
- Gamma spectrometry
- Standards and legislation
- ALARA and safety culture

Referring to questions such as *'what is radioactivity?'*, *'how can we use it?'* and *'how can we protect ourselves against it?'*, the series starts with an introduction to nuclear physics that is then linked to a practice-oriented part on radiation and dose measurements and spectrometry. The module on biological effects of ionizing radiation presents an understanding of the effects of high and low level doses of ionizing radiation on the human body. The series is completed with a state-of-the-art overview of standards and legislation and a rationale on ALARA and safety culture, including a demo session with virtual dose assessment software tools.
When composing a custom-made program, the course could start from this basic series, but some modules may be omitted and other more specialized modules can be added upon request.



### Specialized modules

The *nuclear and radiological expertise modules* are follow-up modules that fit in directly with the basic course series, but provided sufficient foreknowledge, they may be taken separately. The series addresses technical practice-oriented issues with a link to radiological protection and relies fully on the nuclear expertise of SCK•CEN. The series include amongst others:

- Transport of radioactive materials
- Radon and increased natural radioactivity
- Ethical aspects of the radiological risk
- Management of radioactive waste
- Internal dosimetry assessment from bioassay measurements
- Quality assurance in nuclear safety
- Decommissioning and dismantling techniques
- Good safety practices in controlled areas (practical training)
- Organization of emergency planning
- Misuse of radioactive materials: prevention and response (safeguards)
- Radiochemistry

### Practical exercises and visits

In the course programs, lectures and practical training sessions can be alternated with visits to relevant laboratories and installations of the SCK•CEN. These technical visits enable to enrich and illustrate the participants' acquired knowledge with the practice of 'real-life' situations, as well with regard to safety culture in controlled areas, as the techniques and know-how of the applications of radioactivity as such. SCK•CEN installations and laboratories that can be visited include:

- BR1, the 'natural uranium – graphite – air' type research reactor;
- BR2, the high neutron flux material test reactor;
- BR3, the first prototype Pressurized Water Reactor in Europe, and the first now in dismantling phase;
- The HADES underground laboratory for waste disposal research;
- The radioactive decontamination wing of the medical services;
- The emergency planning and follow-up room;
- The whole body counter laboratory (antropogammametry);
- The radiobiology and microbiology laboratories;
- The radioecology laboratories;
- The nuclear calibration services.

### Practical organization



The international school for Radiological Protection is based on the site of the Belgian Nuclear Research Centre SCK•CEN in Mol, Belgium. The regions of the municipality of Mol and the adjacent municipality of Dessel have a historical concentration of nuclear activities of more than half a century, hosting research, nuclear fuel fabrication and waste treatment and storage.

All installations and labs that are taken up in the list of possible technical visits are located on the SCK•CEN site. On request, the course lectures can also be organized in the SCK•CEN offices in Brussels, or at the venue of the trainees, eventually completed with technical visits to laboratories and installations on the technical domain of SCK•CEN in Mol.

### Lecturers

Among the isRP lecturers are technicians, physicists, biologists, medical doctors, engineers and social scientists who all bring insights and ideas from their specific background into the course programs. As SCK•CEN staff members, they have a solid knowledge and experience in their field, and can thus directly transfer their theoretical knowledge and practical experience into the various courses.

## Transdisciplinary aspects

Understanding the benefits and risks of radioactivity requires technical insight and training, but also an insight in the context and a sense for the social and philosophical aspects of the situation. isRP concentrates on how to integrate this transdisciplinary approach in education and training programs.

In cooperation with the SCK•CEN PISA group (program of Integration of Social Aspects into Nuclear Research), isRP has build up experience with the theory and practice of participation and involvement in technology assessment and has set up a course module on ethical aspects in radiation protection. On various occasions, the two groups organize round tables, workshops and focus groups with schools and local communities, and this on topics such as medical applications of radioactivity, (nuclear) energy policy and radioactive waste management.

## Policy support

The implementation of a coherent approach to education and training becomes crucial in a world of dynamic markets and increasing workers' mobility. Through networking and participation in international programs, SCK•CEN contributes to a better harmonization of education, training practice and skills recognition on a national and international level.

Covering electricity production, medicine and several activities within the non-nuclear sector the spectrum of applications of ionizing radiation is very wide. Although working with a variety of responsibilities and specific professional aims, practitioners have a triple common need:

- basic education and training providing the required level of understanding of artificial and natural radiation,
- a standard for the recognition of skills and experience,
- an opportunity to fine-tune and test acquired knowledge on a regular basis.



From an executive perspective, education and training are undoubtedly the two basic pillars of any policy regarding safety in the workplace. The radiological protection rationale that serves as the basis for this policy is the same all over the world, going beyond cultural differences and disciplinary applications. In this sense, the implementation of a coherent approach to education and training in radiological protection becomes crucial in a world of dynamic markets and increasing workers' mobility.

Through networking and participation in international programs, SCK•CEN aims to contribute to a better harmonization of training practice and skills recognition on a national and international level. In this frame, specific issues of interest to SCK•CEN in general and the isRP in particular are the standard requirements for course programs and educational material, the development of transdisciplinary training programs, e-learning and distance learning, the link between radiation safety and conventional safety, the organization of experience feedback, international exchange of knowledge and experience and the sharing of lecturers, training facilities and educational source material. These are the topics covered in European networks such as EUTERP (European Training and Education in Radiation Protection Platform – www.euterp.eu) and ENETRAP (European Network for Education and Training in Radiation Protection – www.sckcen.be/enetrap2), in which SCK•CEN is playing a prominent role.

# Lessons learnt from an accidental release of 45 GBq $^{131}$I in Fleurus, Belgium

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## Abstract

On August 22, 2008, a cloud of $^{131}$I was released from the Institut des Radioelements (IRE), a producer of medical isotopes located in Fleurus, Belgium. The peak of the release took place in the weekend of 23-24 August and was followed by a smaller, continuous release which lasted for several weeks.

Several measures were taken after notification of the release to the Federal Agency of Nuclear Control, the Belgian nuclear safety authority. The nuclear emergency plan was activated on a N2 level. Under this emergency plan many environmental samples were taken and analysed with the purpose of verifying whether there was no risk for the population to obtain a significant dose via the food chain. Air samples were taken to confirm that no significant persistent release of $^{131}$I was still occuring. This air monitoring was performed just after notification of the release and during major replacement work of the filter systems of the isotope production plant.

The Belgian Nuclear Research Centre SCK•CEN collected and analysed many of the environmental samples, performed the air monitoring and participated in the evaluation cell of the National Crisis Centre. In the course of these activities and in the period after the immediate crisis, some points were discovered that could be improved. Most of these findings dealt with:

- acquisition and measurement capacity of environmental samples
- Public communication
- separation of different tasks in the field
- communication between experts
- availability of expert knowledge

This paper elaborates on the main aspects of the SCK•CEN participation in the emergency response of this incident and draws important lessons to dealing with similar situations in the future.



## Introduction

In nuclear emergency management a relatively low number of real incidents and accidents are available for training and improving the emergency plans. Therefore nuclear emergency management relies relatively heavily on theoretical exercises, based on calculations and hypotheses. A real incident or accident may provide a strong confrontation with the existing emergency plans, not only for the technical part, but also including the high pressure from the authorities, public and press.
On August 22, 2008, a cloud of $^{131}$I was released from the Institut des Radioelements (IRE), a producer of medical isotopes located in Fleurus, Belgium. The peak of the release took place in the weekend of 23-24 August and was followed by a smaller, continuous release which lasted for several weeks.
The release was followed by the activation of the Belgian nuclear emergency plan, under which e.g. many environmental samples were taken and analysed to see whether there was any radiological risk for the population.
The Belgian Nuclear Research Centre SCK•CEN collected and analysed many of these environmental samples and performed several other duties in the nuclear emergency plan. In the course of these SCK•CEN activities and in the period after the immediate crisis, several points were discovered that could be improved in the working of SCK•CEN. This will be discussed in the following chapters.

## Description of the incident

The release of $^{131}$I started on August 22, 2008. The total release was 45 GBq $^{131}$I. The peak of the release took place in the weekend of 23-24 of August and was followed by a smaller,

continuous release which went on for several weeks. The release is shown graphically in figure 1.
The cause of the release was the mixing of three different waste streams from small waste tanks (two of 50 l and one of 23 l) into one main waste tank (2700 l). This caused a chemical reaction that produced $I_2$ gas. The total source term in the main tank was estimated to be 37TBq. The main part was absorbed by the filters, but 0.1 % was released through the stack of the installation.
Mixing of the different waste streams was common practice. However, this time all the three small waste tanks were transferred at the same time onto the main waste tank, while normally this was done one small waste tank at a time. Furthermore the main waste tank was originally almost empty (200 l), so the remaining concentrations were higher than usual. Simulations showed that certain chemical reactions that would produce $I_2$ were likely to happen.

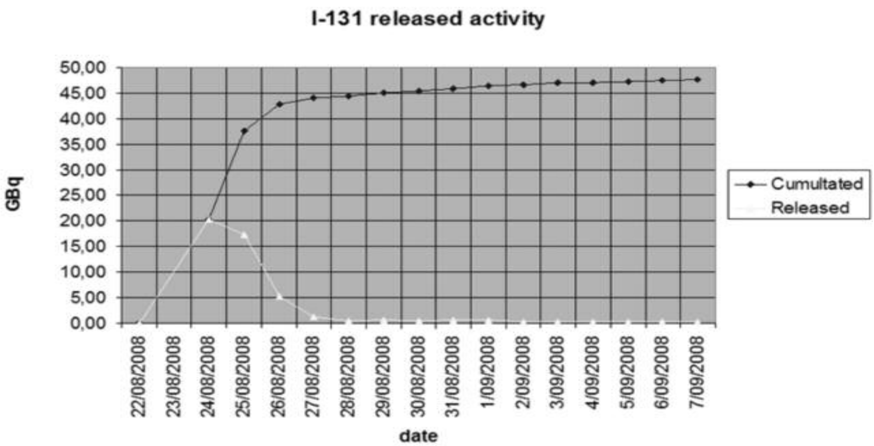


**Figure 1. Released and cumulated activity of $^{131}$I from the IRE incident [FANC1]**



The incident remained unnoticed during the weekend of 23-24 August. It was observed on Monday 25 August by the safety engineer of IRE, who started his duty. The Belgian authorities (Federal Agency of Nuclear Control, FANC) were notified of the release at 17:30 Monday afternoon. Earlier on Monday IRE had already notified the TSO, Bel V [FANC1].

**Simulations of the incident**

On its own initiative SCK•CEN performed calculations with several dispersion models and decision support systems. These included Noodplan, a home-made model that is used by most Belgian nuclear facilities for emergency planning, HOTSPOT, a simple dispersion model, and RODOS, a decision support system developed with support of the EC.
The calculations with the different models showed a good agreement with each other and with the results of the measurements that were performed. Figure 2 shows just as an example results from RODOS calculations. The obtained results have not been analysed in detail and will not be further discussed in this paper.

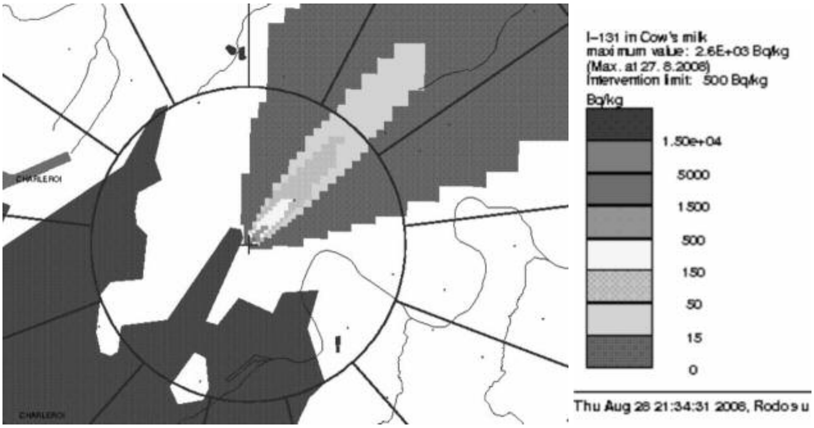


**Figure 2. Results of a RODOS calculation of a release of 45 GBq $^{131}I$**

## The Belgian nuclear emergency plan and the role of SCK•CEN

Figure 3 shows schematically the structure of the Belgian nuclear emergency plan. The national crisis centre CGCCR consists of several cells which have their specific functions.
COFECO is chaired by the Minister of Interior Affairs or its representative and is responsible for taking decisions how an accident should be dealt with. It is supported by several cells for advise: ECOSOC for advice on social-economic consequences of countermeasures; INFOCEL for advice on communication to the public, CELEVAL for advice on radiological consequences of the accident and countermeasures. CELEVAL manages the measurement cell that performs measurements in the field and operates the TELERAD system for direct measurements of radioactivity.
By Royal Decree SCK•CEN provides a radiological expert to CELEVAL, a local measurement coordinator and a measurement team for in-situ measurements and sampling.

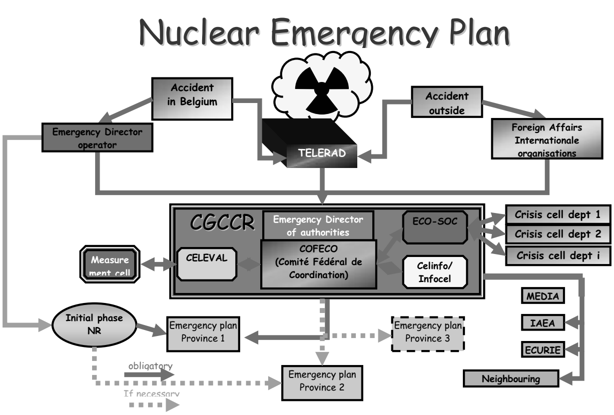


**Figure 3. Structure of the Belgian nuclear emergency plan**

On Wednesday 27 August the first three samples of grass were taken in the close vicinity of IRE by FANC. These samples were analysed at the Scientific Institute of Public Health ISP/WIV and the results were made available to the authorities on Thursday 28 August. They showed contaminations that could result in countermeasures for the food chain.
After the national nuclear emergency plan was activated on Thursday 28 August in the late afternoon, SCK•CEN was asked to prepare for the next day an intervention team for measurements and sampling. Instructions would follow the next day.
On Friday 29 August SCK•CEN sent out two teams, one for performing direct measurements and one for sampling. Two teams were sent since no instructions were received yet and it was not clear what would be asked by the authorities. Upon arrival at IRE, instructions were obtained to perform at specific locations air sampling and to perform in a quarter of a circle doserate measurements of the ground contamination. At 15:00 the coordinates were received of the locations were samples of grass or vegetables should be taken. These were five locations that were visited consecutively. In function of the availability, samples of grass, cornleaves and lettice were taken. The upper leaves of the corn were sampled to take the maximum contamination.
The samples were taken at the end of the day to SCK•CEN for sample preparation and measurement by gamma-spectrometry. Measurements were performed during the evening and night in order to provide the results to the authorities at the beginning of the next day.
Similar sampling and measurement campaigns were held at Sunday 31 August, Tuesday 2 September, Wednesday 3 September and Thursday 4 September. At the end of each day samples were taken to SCK•CEN in order to provide measurement results at the beginning of the next day. On Thursday 4 September an air sample was taken on active charcoal.
On Monday 1 September and Tuesday 2 September SCK•CEN performed, together with the University of Liège, a thyroid measurement campaign on the population of Lambusart, a village northeast of IRE. This campaign is reported in a separate paper [van der Meer et al.].
On Friday 5 September it was decided to do another air sampling campaign, since at that day an additional filter group was placed between the waste tank and the stack.




**Figure 4. Ground contamination measurements (left) and air sampling (right)**

**Figure 5. Sampling of vegetables in local gardens**

## Countermeasures that were taken [FANC2]

As mentioned beforehand, the incident remained unnoticed during the weekend of 23-24 August. It was observed on Monday 25 August by the safety engineer of IRE, who started his duty. The Belgian authorities (Federal Agency of Nuclear Control, FANC) were notified of the release at 17:30 Monday afternoon. Earlier on Monday IRE had already notified the TSO, Bel V.
On Tuesday 26 August inspectors of FANC and Bel V visited IRE and ordered not to start any new production batch. Mobile monitoring systems were installed around the installation.
On Wednesdat 27 August FANC notified the IAEA and rated the incident on level 3 of the INES scale. FANC also collected grass samples in the close neighbourhood of the plant.
On Thursday 28 August results of the measurements became available, indicating that at certain locations the limits for countermeasures for the food chain could be passed. This triggered the activation of the national nuclear emergency plan on 17:00 on the level U2, implying no direct risk for the population but potential countermeasures for the food chain. A recommendation was issued that the population should not use vegetables or fruit from their own garden nor should use rain water in the region between 0-5 km northeast of IRE. Selling milk produced in the same region was also prohibited.
On Friday 29 August the sale of milk was again allowed, based on measurements on milk carried out on behalf of the Federal Food Agency. The other countermeasures remained in force.
On Saturday 30 August new measurement results were available. Based on the results, the affected region was reduced from 0-5 km to 0-3 km, while rainwater could be used again. The recommendation not to consume vegetables and fruit from the own garden remained.
On Saturday 6 September the remaining countermeasures were lifted, based on the results of all the measurements performed in the course of that week. Furthermore the emergency level was reduced from level 2 to level 1.
On Friday 12 September the national nuclear emergency plan was lifted.

## Possible improvements

Many aspects of this incident can be used to improve the working of the nuclear emergency plan. In this paper we will mainly limit ourselves to propose improvements to the duties of SCK•CEN in the framework of the Belgian nuclear emergency plan as described above.

Before the IRE incident it was always assumed during exercises that one measurement team would be able to perform all actions in the field. Very soon it became clear that it was very cumbersome to send a team in the field with a combination of tasks. Different tasks like performing direct doserate measurements and sampling interfere quickly with each other and are best seperated, unless very little samples have to be taken. Separation of tasks also improves considerably the flexibility of the teams for answering to specific requests from the authorities.
Three different measurement teams have been defined after the incident: an intervention team responsible for direct measurements (doserate, ground contamination, air activity sampling), a sampling team for biological sampling (grass, vegetables, milk, water, ..) and an AGS team (Aereal Gamma Survey). The latter is supposed to operate from a helicopter or airplane, but at present it is operated by car.
Due to the fact that the intervention team and AGS team rely partly on the same expertise, SCK•CEN may at a certain moment not be able to provide experts for all teams in case of a protracted incident that requires measurements for e.g. several weeks.

*acquisition and measurement capacity of environmental samples*

The IRE incident was a relatively small incident that contaminated only a limited area. Nevertheless it resulted in a serious demand on the capacity of the sampling team and the gamma-spectrometry measurement lab.
A larger incident in Belgium would require more resources from SCK•CEN. Both sampling and measurement capacity should be increased in that case.
A more optimized use of sampling and measurement teams seems possible. During the IRE incident the sampling locations and types were based on the collective results of the previous day resulting in a discontinuous sampling/measurement process (sampling in afternoon, measurements over night, analyses next morning + definition new sampling locations/types, new sampling in afternoon, ...). A more continuous sampling/measurement strategy in combination with the use of pure logistic teams for e.g. the transport of samples could already result in an optimization of sampling/measurement capacity.
Not all sampling teams had during the incident access in the field to software for the optimization of the route between a set of sampling locations (typical 10-20 locations). A general procedure on the transfer of measurement locations/type and measurement results was missing.
Sampling capacity was already increased by establishing a dedicated sampling team. Further expansion of the capacity is envisaged by increasing the number of sampling teams. This is only feasible in case the pool of persons that have sampling experience is increased. Expansion of this pool is envisaged by the participation of more people in the regular sampling campaigns in the framework of the surveillance of the Belgian territory. Additionally written procedures for sample taking have been developed that were lacking during the IRE incident. This will provide a better guarantee that samples will be taken in a similar way.
For several types of samples (mainly vegetation) the preparation of the samples will prove to be a bottleneck rather than a gamma-spectrometry measurement. At present preparation of samples deals with samples from the surveillance programme, that have no or very little radioactive contamination. Preparation rooms for these samples should not be used in case of contaminated or suspected samples. A dedicated room should be established. In case of the IRE incident an ad hoc solution was found by using a room with a ventilated box in a controlled area, but this room will not be sufficient for large quantities of samples.

Once prepared, samples can be measured in a rather short time since they are either sufficient active to give a good signal or will not give a significant signal from which the onclusion will be drawn that the activity is below a certain limit. However, clear measurement procedures still have to be developed for this case.
More exotic contaminations like beta or alpha contaminations will prove to be much more difficult to deal with, since the preparation time for these measurements are much longer than for gamma-spectrometry. Again specific measurement procedures have to be developed for these contaminations.

*Public communication*

It was inevitable that teams in the field would encounter representatives of the media. Although the communication about the incident should go exclusively via the national crisis centre, the field teams were sometimes forced to answer at least partially to specific questions. In a similar way the people whom were asked to provide their vegetables had many questions and also these questions should be answered by the teams in an adequate way in order to guarantee a continuous public support for the sampling campaign.
So although the principle of crisis communication demands one clear voice of the authorities and therefore demands a central spokesperson, the people in the field are exposed to questions from the media and should have adequate means/training to respond to these questions, either by providing clear answers or referring to a central spokesperson.

*communication between experts*



Several types of communication could be distinguished:

- communication between experts for passing through information. This was mainly important for the evaluation cell of the national crisis centre. A summary of what was discussed during the day had to be given to the expert for the next day. This was done either in the form of a written report or orally by phone
- specific questions from the evaluation cell had to be dealt with by measurement experts. E.g. the request for a thyroid measurement campaign had to be supported by estimates of the detection limits of the available equipment and the amount of people that could be measured. This type of questions were handed over to a central scientist at SCK•CEN and then discussed internally with the relevant experts. An answer was provided in the form of a short note to the SCK•CEN radiological expert
- communication with the measurement team was dealt with by the measurement cell coordinator, an official function executed by SCK•CEN that takes care for the transfer of information between the federal evaluation cell and the measurement team. Coordinates of sample locations and type of samples are typical data to communicate to the measurement team.

Communication was often performed by cellular phone. This worked well, but in case of a major crisis it is envisaged that the cellular phone networks will be overloaded and cannot be used. Therefore extra phones have been purchased that function on a secure and reliable network.

*availability of expert knowledge*

Both for making available an expert for the evaluation cell of the national crisis centre and for providing an expert for coordination of the measurement team, SCK•CEN has established a duty cycle. Each expert fulfills a duty of one week and hands it then over to the next expert.

It was noticed that the establisment of such a duty cycle is not a warrant that during a real crisis the expert functions can be fulfilled 24 hours per day and 7 days per week. The duty cycle is only a warrant that SCK•CEN will be able to provide an expert the moment an emergency call comes in for the next 8-12 hours. An expert shift had not been established.
During the incident SCK•CEN provided an expert for each evaluation cell meeting, based on the availability within the pool of experts at SCK•CEN. The decision who would participate in a meeting was normally taken one or two days before that meeting took place, but it cannot be denied that this method of working implied a certain form of improvisation.
The same was true for the establishment of the measurement teams. This was done on a daily basis and subject to the demand from the national crisis centre. Since only the coordinator of the measurement team is in a duty cycle, but not the team members themselves, here the level of improvisation tended to be higher than for the evaluation cell expert.
It has been recognised that the number of available experts should be enlarged in several domains: radiological experts, sampling team members, measurement analysts and experts (both for in the field and at the labs). However, in view of the limited resources available for this enlargement it should also be recognised that a certain level of improvisation will always be present.

**Conclusions**

The IRE incident did not cause any radiological harm to the general public. It is an interesting case to provide some lessons learnt for the emergency preparedness organisations in Belgium and possibly abroad.
The tasks that had to be executed in the field required one person (or team) for one job. Too many different tasks divide the attention people can devote the these tasks and imply a risk for making mistakes.
Sampling procedures have to be improved in order to be able to take more samples in a uniform way. Dedicated rooms for active samples should be present where many samples can be processed.
Gamma-spectrometry will not provide a bottleneck in measuring samples. However, due to the long preparation time alpha and beta measurements may require dedicated measurement procedures for large numbers of active samples.
Public communication is an important tool to provide the necessary support of the public for the measurement campaigns and countermeasures. During the sampling campaign SCK•CEN encountered full support of the public to provide samples from gardens.
Communication between the experts was satisfactory, but should be performed in a more standardised way by e.g. providing meeting reports after each day.
Availability of sufficient experts remains a difficult problem for relatively small organisations in a small country. Improving procedures will solve this partly, but a certain reliance on improvisation will remain.



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