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Le douzième congrès de l'IRPA (International Radiation Protection Association) a eu lieu à Buenos Aires du 19 au 24 octobre 2008
Ce numéro 3 du Volume 33 des Annales de l'Association belge de Radioprotection reprend des articles d'auteurs ou co-auteurs belges.

Van 19 tot 24 oktober 2008 vond te Buenos Aires het twaalfde congres van de IRPA (International Radiation Protection Association) plaats.
Dit nummer, n° 3 van Volume 33 van de Annalen van de Belgische Vereniging voor Stralingsbescherming, herneemt de artikels met Belgische auteurs of medeauteurs.

IRPA 12

BELGISCHE BIJDRAGEN
PARTICIPATION BELGE

SOMMAIRE **INHOUD**

Annalen van de Belgische Vereniging voor Stralingsbescherming, Vol.33, nr.3, 2008
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External radiation dose to ward staff from nuclear medicine patients: An extended real time survey

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Abstract. Ward staff in hospitals are often exposed to ionizing radiation from in-patients who have been injected by radiopharmaceuticals.
Published data concerning this issue are mostly based on dose-rate measurements and occupancy factors. For this reason the Radiation Protection Office of the University Hospital of Brussel (UZ Brussel) started a study in order to assess the workaday reality concerning the external radiation dose.
During 6 months 70 ward staff members were monitored during their daily tasks by means of thermoluminescent detectors (TLDs) that were attached on their hospital identification card. Additional TLDs where placed in various hospital and domestic locations to register different background levels. TLDs were calibrated in a secondary calibration laboratory. Calibrations were performed with the 250 keV ISO narrow X-ray spectrum. Simultaneously the activity and type of radiopharmaceutical entering the wards as well as individual workload of the staff members was recorded. Specific guidelines prevented loss of data and registration of exposures that where not job related.
Despite the relatively high amount of activity entering in some wards, only 4 staff members received a dose that exceeds the significance level above the average background.
Although the exposure to external radiation is very limited, additional exposures from radioactive contaminations can occur. The latter exposure pathway to ward staff could not be quantified during this study but can easily be avoided if the need for hygienic measures is emphasised.
The results of this survey can help to encourage risk communication regarding the radiation exposure from nuclear medicine patients, which is presently nonexistent in many hospitals. This communication is extremely important to temper total indifference as well as radiophobia.

KEYWORDS: nuclear medicine, ward staff, radiation protection

1. Introduction

During nuclear medicine procedures a patient is injected by radiopharmaceuticals and consequently acts as a radiation source during and after these procedures. The radiation dose to nuclear medicine workers is described in many publications, but the exposure to individuals also happens outside the nuclear medicine department. Among these critical groups we can consider individuals inside the hospital and outside the hospital such as ward staff, porters, utltrasonographers, family members and many others. [1]. A considerable number of patients, especially high dependency patients, are not discharged from hospital but return to the ward and in this way ward staff members can be the most exposed individuals outside the nuclear medicine department. Previous publications indicate that the exposure to ward staff mostly stays under the dose limit for the public but [2] can become problematic when nursing staff has to take care for high dependency patients [1].
These studies [3-4] use different methods to estimate the dose to medical staff each having the disadvantage that the recorded dose is specific to the condition under which it was measured. To be able to record the actual exposure to the ward staff we introduced a more direct method over a long term period.

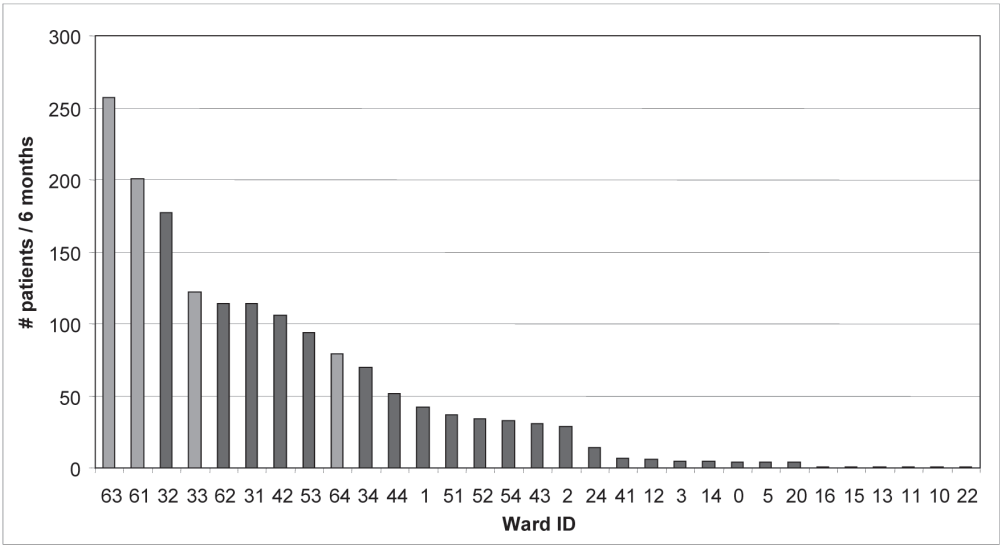
2. Material and Methods

Physical condition of the in-patients are very variable (anatomy, incontinence, stoma,…) which causes problems to determine the correct effective half-live by measuring dose rates. Results obtained by dose rate measurements are often not suitable to assess the realistic exposure to critical groups, covering all different nursing tasks, patient condition and working situations. Real time measurements could be performed by providing ward staff members with a TLD during a six months period. This long period intercepts the background fluctuation and covers most possible exposure pathways.
Since the use of ordinary TLD-badges asks for discipline and can influence the personnel's behavior towards nuclear medicine patient, the TLDs where discreetly integrated to the personal identification badge. The TLD's attached on this badge were calibrated to Hp(10) using the 250 keV ISO narrow X-ray spectrum.
From a resident study we could selected 4 departments where numerous nuclear medicine patients are hospitalized; cardiology, endocrinology, neurology and geriatric ward. 70 ward staff members with different tasks (nurses, logistic workers and physiotherapists) where wearing a TLD on their badge during 6 months. During the same period TLDs where also placed in each ward office. Since the nursing staff members spend only an average of 8 hours in the ward, additional TLDs were placed into cars, offices and private homes to evaluate background influence (shielding, construction materials).
A number of worker- and patient-related parameters can influence the order of magnitude of exposures. Worker parameters such as full time, part time, day-, night or weekend shifts were noted.
The number of patients and the type of nuclear medicine procedure represent the most important patient related parameters and were carefully recorded for each ward. The level of dependency, which can be very important for possible exposures, was not taken into account since this level can vary for a single patient during the hospitalisation period.
Each staff member received guidelines to prevent loss of data (TLD warming up) and the detection of radiation not in relation to daily tasks (medical exposure).

3. Results

During the six months period 1649 patients entered the different wards of UZ Brussel. In the selected departments, cardiology, endocrinology, neurology and geriatric ward, respectively 257, 203, 122 and 79 (Figure 1) patients were hospitalised.

Figure 1: Distribution of nuclear medicine patients over the different wards in UZ Brussel



The fact that ^{99m}Tc is the most used radionuclide in nuclear medicine is confirmed by multiplying the different nuclear medicine procedures with the corresponding reference activities [5]. As a result a total activity of respectively 162, 122, 82 and 50 GBq could theoretically enter the cardiology, endocrinology, neurology and geriatric ward. (Figure 2). The real activity that enters the wards is in fact very difficult to determine due to the combination of different effective half-lives of the radiopharmaceuticals and the moment of return of the patient from the nuclear medicine department.

Figure 2: Maximum amount of activity that could enter the selected wards during the 6 months period

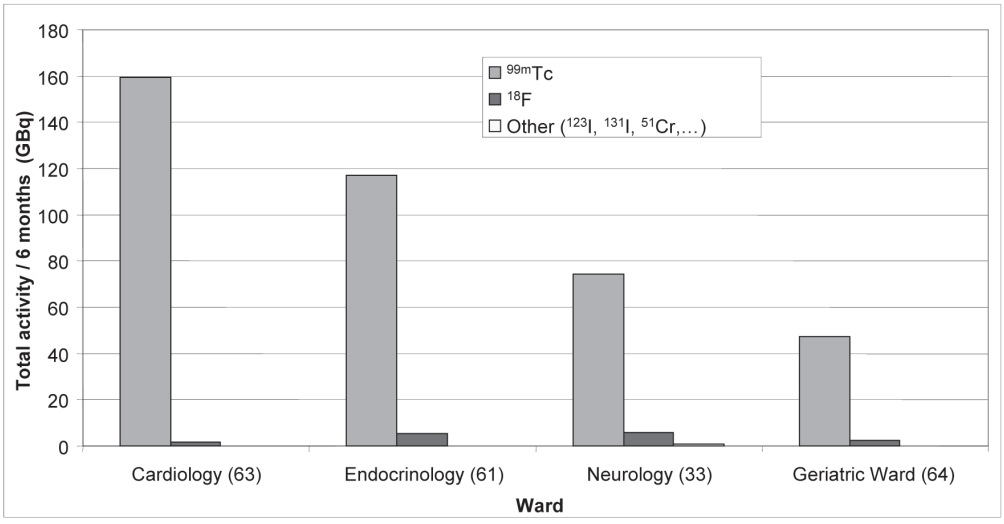
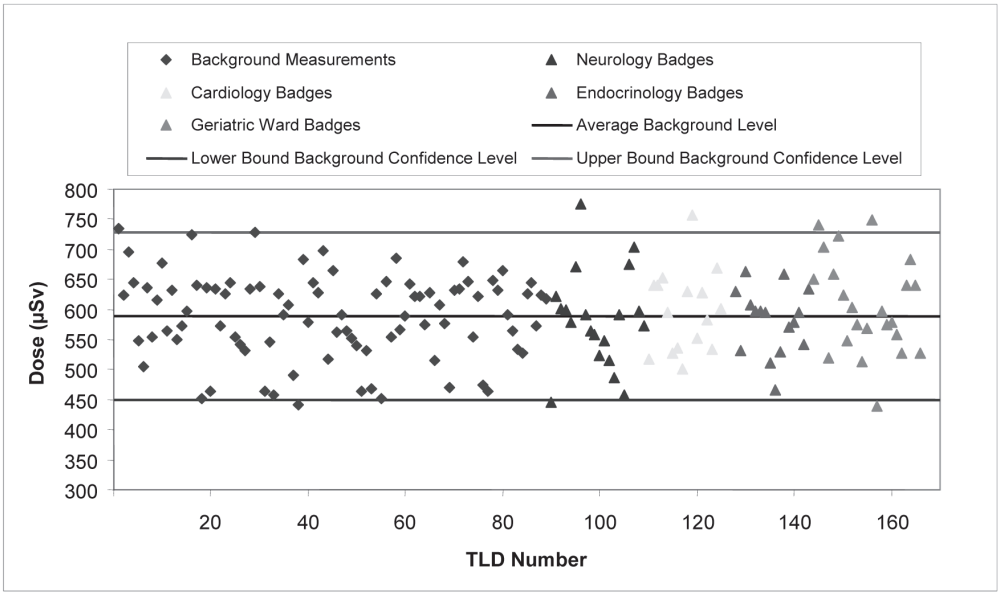


Figure 3: Dose distribution of background measurements and staff monitoring



The total measurement period of the TLD's was 231 days since the time needed for providing, collecting and the transfer for read-out covers more than the 6 months period.
In total 89 TLDs were used for background level detection, 44 TLDs were put aside in the 4 different ward offices, 45 TLDs were spread over different domestic locations. The background results show a normal distribution with an average value 589μSv over the measurement period of 231 days and a 95% confidence level of 728μSv (Figure 3).
Taking into account the background radiation, only 4 staff members received a dose slightly higher than the confidence level of the background fluctuation. The highest dose of 186μSv above the average background can be due to the fact that this person acted as fellow traveller of a family member during several hours after an ambulant radionuclide therapy with ^{131}I.

4. Discussion and conclusion

This study where 70 ward staff members were monitored during a 6 month period, confirmed that the external radiation dose to ward staff from diagnostic nuclear medicine procedure is rather low. For only 4 personnel members out of 70 the dose was slightly significant higher than the background level. However, it should be stated that during this 6 months survey not a single low-dose therapeutic procedure was recorded where the patient entered one of the 4 wards. Moreover, besides the external exposure there is also a risk for contamination which is not monitored during this study and which is almost impossible to carry out in practice. But, in relation to the low level of external exposure and due to the general hygienic hospital rules, it is possible to reduce the contamination risk to a minimum. Previous studies are mostly based on dose rate measurements and mathematical models [3-6] and find that the average dose to members of the ward staff is 24 μSv for a single 8h shift [6]. Taking care for high-dependency patients or partially helpless patients a dose of 112 μSv [3] a day can be reached. Gomez stated that working in a cardiology ward or internal medicine section can lead to an annual dose of 518 μSv [7].
This study uses an integral dose method and indicates that, due to background fluctuations and the long-period survey, very few significant exposures can be found even in cases where 500 outpatients per year are hospitalised in a single ward.
The introduction of strict radiation protection procedures is consequently not appropriate for diagnostic procedures since they may result in unnecessary restrictions on clinical practice. Nevertheless it is important to inform medical staff correctly to prevent total indifference to radiation protection on the one side, to radiophobia on the other side.

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TELERAD: the Radiological Surveillance Network and Early Warning System in Belgium

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Abstract. The TELERAD network is primarily a measurement and early warning network. Its 212 stations constantly measure the overall radioactivity of the air, atmospheric dusts and river waters (Meuse, Sambre and Molse Nete) on the Belgian territory. These stations are linked to a centralised system that is automatically alerted in case an abnormal rise in radioactivity level is detected. The TELERAD network is supplemented by meteorological masts (10 meters and 30 meters height), which measure wind speed and direction, and by a set of mobile stations that can be deployed at any location on the territory. In the event of a nuclear accident, the discharge of radioactive substances into the atmosphere could lead to the launch of the nuclear emergency plan foreseen by the authorities. The TELERAD network would then play a crucial role in assessing the gravity of the accident, supporting decision making, optimising interventions and measures to be implemented to avert the effects of the accident and, subsequently, to remedy them, as well as informing the population on an ongoing basis. In normal circumstances, the TELERAD network measures the ambient dose rate due to external gamma radiation. This dose rate is essentially linked to the level of natural radioactivity.

KEYWORDS: environmental monitoring, early warning system.

1. Introduction

The TELERAD network is the automatic remote radioactivity measuring network in Belgium. It comprises 212 stations, which constantly measure the radioactivity of the air and river waters.

The stations are distributed throughout the entire country, around the Tihange, Doel, Mol and Fleurus nuclear sites, as well as in the urban areas close to these installations and in those around the Chooz nuclear site in France. The distribution of the measurement stations over the Belgian territory is shown in Fig. 1. These stations are linked to a centralised system that is automatically alerted in case an abnormal rise in radioactivity level is detected.

2. Objectives of the network

The TELERAD network is a measuring and early warning network and, as such, pursues the following two major objectives:

- *The continuous recording* of measurements to provide all necessary statistical information on the level of radiation found in the country;
- *The setting off*, without delay, of an alarm to signal the exceeding of a warning threshold.

TELERAD is thus an alarm network that enables the real-time detection of any abnormal situation, which may lead, at its highest level of severity, to the activation of the national emergency plan for nuclear risks in Belgium. In the event of a nuclear accident, TELERAD will play an important role in supporting decision making, optimising interventions and countermeasures implemented by the relevant authorities, as well as keeping the country's citizens informed on an ongoing basis.

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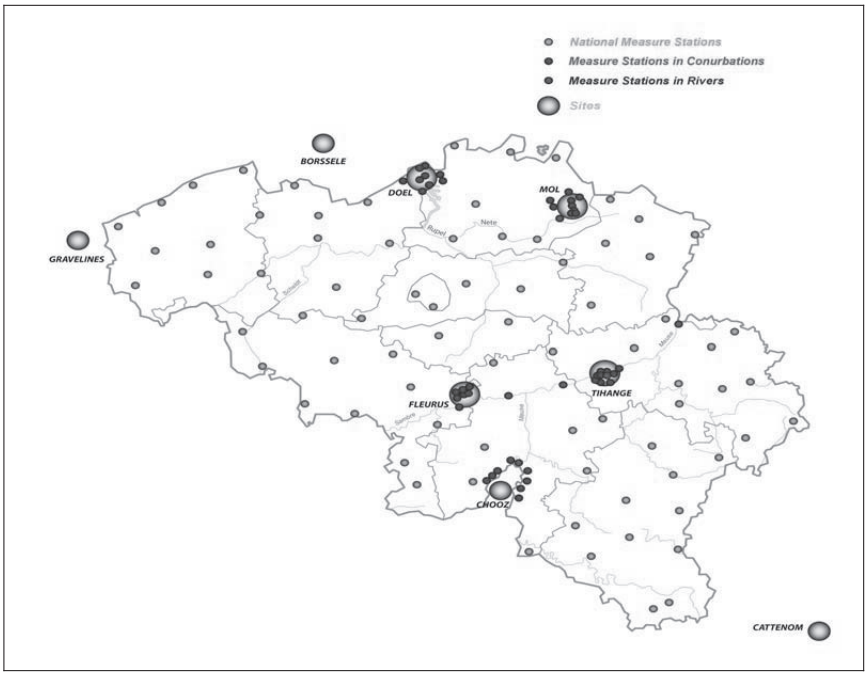
Figure 1: Distribution of the measurement stations over the Belgian territory

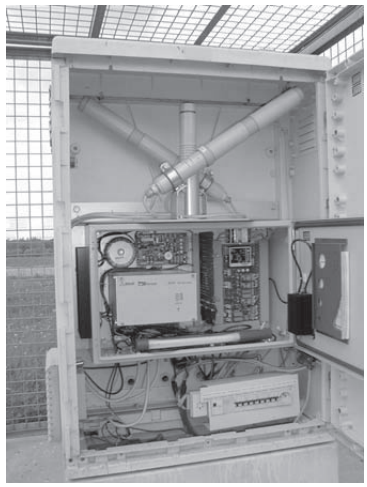


3. TELERAD as a radiological instrument

The stations used in the TELERAD network for measuring radioactivity in the air are of three types.

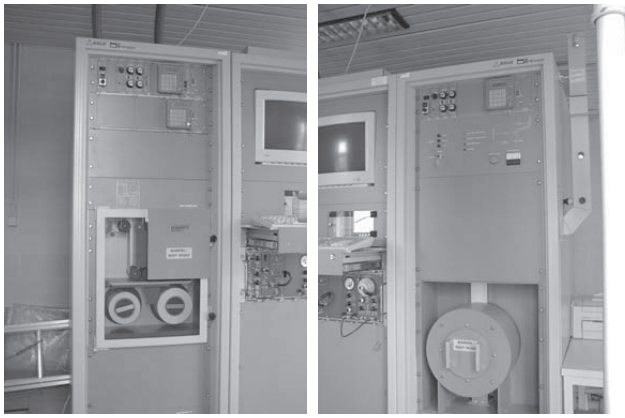
The **dosimetry stations** for measuring the *ambient gamma radioactivity*, of which there are 128 on the territory and 61 around the nuclear sites of SCK•CEN (Mol), Tihange, Doel, IRE and around the Givet area for monitoring the Chooz nuclear site. Fig. 2 gives a view of the three detectors and the electronics inside this type of measurement stations. Each of these stations is furthermore equipped with a rain detector which provides information about the presence and duration of rainy periods.

Figure 2: Exposed dosimetry station with view of its 3 detectors and connected electronics



The **aerosol stations**, of which there are 7, for measuring the radioactivity of dusts suspended in the air (aerosols and fine particles), which determine the total alpha and total beta radioactivity. Three aerosol stations (situated on the sites of SCK•CEN, IRE and FANC) are linked to a gamma spectrometry unit. The left part of Fig. 3 shows the alpha/beta measuring unit with a view of the unreeling filter tape which collects the dusts and particles impacted when air is pumped. These stations are supplemented by a **unit measuring radioactive iodine** on the aerosols and the air particles when a pre-determined threshold of beta radioactivity is exceeded. If the warning thresholds for total beta activity are exceeded, active carbon cartridges, intended to trap the radioactive iodine, are automatically measured after pumping in the outside air. The right part of Fig. 3 shows the detector in its casing (cylinder) with the tube containing the active carbon cartridges on the right.

Figure 3: View of an aerosol station: total alpha and beta counter (left) and iodine counter (right)



TELERAD also has 6 **river stations** which continuously measure the *gamma radioactivity of river waters*. These stations are installed close to the three rivers receiving discharges from nuclear sites and waste waters from major urban centres (combining research centres, universities and hospitals): the Meuse, the Sambre and the Molse Nete. These stations are large containers (see Fig. 4) from which an inlet and an outlet pipe allow river water to be pumped to the detector and returned after the radioactivity has been measured.

Figure 4: Outside view of a river station with inlet and outlet pipes

Inside is a gamma spectrometry unit (NaI crystal coupled to a two channel analyser) housed in its own tank, surrounded by a strong lead screen, protected by a stainless steel casing in which the water pumped from the river enters and leaves (Fig. 5). To the left of the gamma spectrometry unit is a large volume water sampler (SwedMeter type) which enables a sample of the water in the pipe to be taken automatically as soon as a pre-set action level is exceeded. This water is stored in a 25-litre flask for subsequent gamma (and beta) spectrometry analyses in the laboratory.

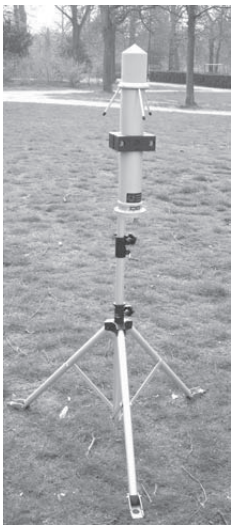
Figure 5: Inside view of a river station: view of the detector and the large volume water sampler and PP MOS

On the far left of Fig. 5, a programmable automatic sampler (Buhler type PP MOS) enables water to be pumped into flasks for gamma, alpha and beta spectrometry (for additional radiologic monitoring of the territory). Fig. 6 shows the inside of the PP MOS with the pumping instruments in its upper section and all the 2.9-litre flasks (12 in total) at the bottom. This fully programmable unit enables pre-determined volumes of water to be collected over a fixed time period and frequency. Above the PP MOS are the counting unit and the high voltage supply of the river station detector.

Figure 6: Exposed view of an automatic sampler PP MOS

Finally, the TELERAD network is supplemented by a set of 24 new mobile stations for the measurement of ambient gamma radioactivity, shown in Fig. 7. These stations - now in a testing phase - will be installed in places to be subjected to more detailed examination.

Figure 7: One of the 24 new mobile stations for ambient gamma dose measurement



The TELERAD network has generated in 2007 a total of 161 alarms without any radiological impact: these alarms have mainly been induced by industrial operations and / or meteorological conditions.

4. TELERAD as a radiological instrument for the nuclear emergency planning

In the framework of the nuclear emergency planning, the TELERAD network gives essential data to the experts who evaluate the radiological situation and who propose countermeasures in case of a radiological incident or accident.

These data will help to assess the gravity of the incident/accident, to optimise interventions and measures to be implemented to avert the effects of the incident/accident and, subsequently, to remedy them, as well as informing the population on an ongoing basis.

Experts analyse the radiological situation by way of a software interface that shows the on line situation and condition of the different stations of the network (see Fig. 8).

Figure 8: Interface available to the experts for evaluating the radiological situation

5. TELERAD as a meteorological instrument

Along the borders and around nuclear sites, TELERAD also has 9 meteorological measuring instruments (wind speed and direction) installed on 10 m masts. There are also 4 additional 30 m meteorological masts located near the nuclear sites measuring wind speed and direction and sunshine. Presence, duration and intensity of rain are also monitored by rain detectors and pluviometers.

These data are essential to detect quickly the origin of any foreign source of radioactivity and, depending on the wind speed and direction, to forecast what regions may be over-flown by a radioactive cloud and at what time this will happen.

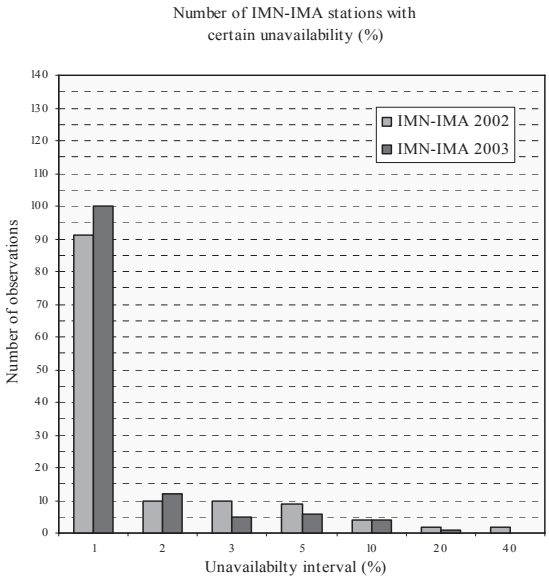
6. TELERAD as an instrument for calculating the external exposure dose rate

In 2004-2005, a study was done by the FANC based on the data of 2002 and 2003 produced by the TELERAD network (accuracy, reliability…). The study led to the conclusions presented hereafter.

The unavailability of the monitoring system, being defined as the time the stations do not produce useful data due to maintenance, malfunction…, is given for some monitoring station in Fig. 9. The overall unavailability of the entire network was 1.7%, respectively 0.9% for the years 2002 and 2003. Knowing that not all stations are out of order at the same time, we can conclude that the territory is effectively monitored continuously.

The equivalent isodose charts from 2002 & 2003 (100% outside occupancy) varied between 0.8 and 1.1 mSv/y (depending upon the region or soil composition) with a maximum standard deviation of 0.4 mSv/y. Comparison of the TELERAD dose rates with data from the European Commission and with calculated dose rates according to soil composition showed that values were of the same order of magnitude (± 10% difference). We therefore can conclude that the dose rate values of the TELERAD network are representative and can be used to calculate equivalent or effective external doses with sufficient accuracy.

Figure 9: Unavailability of the IMN and IMA measurement stations for 2002 and 2003



Using the TELERAD outdoor dose rate data for estimating rapidly the annual effective dose received by man with indoor-and outdoor activities of respectively 80 and 20% displayed promising results. After subtraction of the cosmic contribution from the measured dose rates, the remaining values were increased by 20% which served as an estimation of the indoor dose rates. The average effective annual dose resulted in a value of 0.76 mSv/y, which is similar to the 0.75 mSv/y from [1] (1% difference). Although it is not a 100% accurate, the procedure has shown to be satisfactory for estimating quickly the annual effective dose with results that are representative within a margin of about 10%.

As the TELERAD network measures a dose rate (μSv/h) continuously – and, as shown in previous paragraphs, data are accurate and reliable - it is possible to calculate the annual gamma exposure dose on a station-by-station basis and represent this in a map, which is shown in Fig. 10. The annual report of the radiological surveillance of the Belgian territory [2] integrates the TELERAD data through this graphical synthesis. The map in Fig. 10 represents the annual external exposure expressed in mSv (external gamma exposure dose) to which the territory is subjected.

An analysis of the exposure map shows that the average gamma exposure dose in Belgium is 1 mSv/year, that it varies from 0.8 mSv/year in the north to 0.9 mSv/year overall in Flanders and 1.1 mSv/year overall in Wallonia and, more particularly, in the Ardennes.

The exposure varies according to the nature of the soil. The doses are generally higher in old terrains made up of rock such as sandstone and schist, which is for Belgium the case in the Ardennes – see the geological map in Fig. 11. In Flanders, where the soil is predominantly made up of sedimentary terrains (sand, alluvium and clay), the doses are lower. It is noted that, in the far south of the country, i.e. a marly, clayey region with sandy-silty layers over a chalk sub-stratum, the dose declines to reach values comparable to those in the north/central part of the country.

Figure 10: Overview of the external annual dose measured by the TELERAD stations

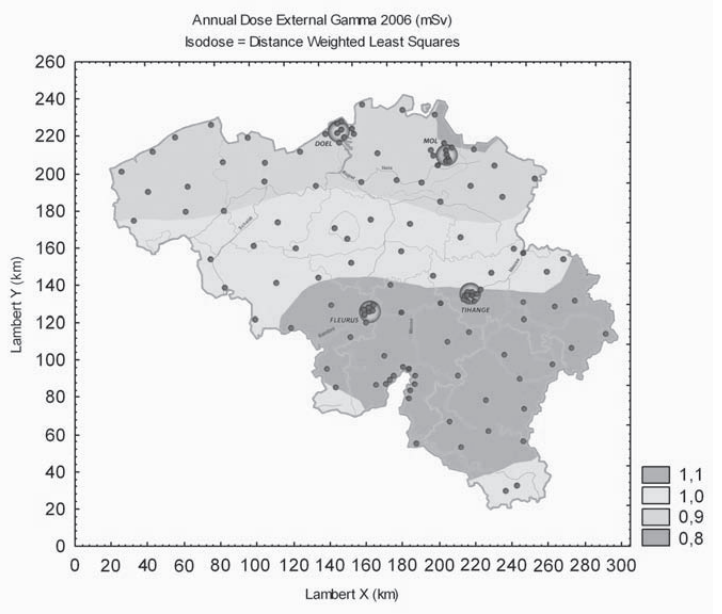


Figure 11: Geological situation of the Belgian territory

7. Modernizations of the TELERAD network

As a result of several technical shortcomings of the original TELERAD network, installed in 1998, the FANC decided in 2004 to modernize the system. These modernizations concerned mainly the ICT and telecommunication part of the system and not the detectors and related measurement systems. The old and new TELERAD systems coexisted for about 2 years.

During 2006 a major external audit of the TELERAD system was performed. Although the results of this audit were positive for the new TELERAD system, some modifications and additions to the system were suggested. Following this audit, the FANC implemented these suggestions and by April 2007, the old TELERAD system was permanently put out of order.

The most important features of the new TELERAD system are discussed hereafter.

The measurement results of all stations are sent every 10 minutes to the central servers and stored in a database. With the old system these data were sent to the servers only once a day, exception for particular stations in case of an alarm. Moreover, the system today uses standard telephone lines (ISDN), whereas the old system used expensive privately leased lines. Hence, in spite of the rise of the total number of communications, the costs related to telecommunication have substantially been reduced.

Furthermore, the experts have access to the measurement results through the Internet. Thanks to the development of a VPN module, the experts can consult the database and evaluate the radiological condition of the territory from any place in the world. From the office they have direct access to the TELERAD servers and from any other place with Internet access, they can use a secured VPN connection. In case there would be no Internet connection available, a wireless GPRS connection still allows consulting the database. In all cases the access is realized through the user-friendly interface shown in Fig. 8, giving a clear overview of the radiological condition of the territory. This overview is based upon a color code indicating the status of each measurement station: green (OK), orange or red (radiological situation), blue (technical problem) …

Thanks to the generalized accessibility to the system and thanks to the development of an automated alarming module, a 24/7 role of duty was organized for immediately analyzing all radiological situations that are detected by the TELERAD network.

The availability of the modernized network is guaranteed by a complete redundant server cluster and database on a back-up site. In case the server cluster at the FANC HQ would not be available, the server cluster at the back-up site automatically takes over all tasks and functionalities. Hence, all manipulations remain at all times possible for the experts.

8. Conclusions

An overview of the current status of the Telerad network, the radiological surveillance network and early warning system of Belgium, was given. Its recent modernizations were discussed and the high availability of the system was presented. It was also shown how the system can be used for calculating the average external exposure to the population, clearly indicating variations in function of the nature of the soil.

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A handbook for the triage, monitoring and treatment of people exposed to a malevolent use of radiation

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Abstract. In the aftermath of the Chernobyl accident European national emergency response plans have been tailored to deal with accidents at nuclear power plants. Several terrorist acts (World Trade Center, New York; Atocha train station, Madrid; suicide bombings) carried out by disaffected groups have shifted the focus to malevolent use of radiation. The radiation exposure can range from very low to substantial, possibly combined with conventional injuries. Therefore practicable tools are needed for an adequate response to such acts and more specifically to address European guidelines covering triage to treatment and long term follow up of exposed people.
The European Commission through the Euratom 6th Framework Programme is co-sponsoring the specific targeted research project TMT handbook. The main objective of this project is to produce a practicable handbook for the effective and timely triage, monitoring and treatment of people exposed to radiation following a malevolent act.
This paper elaborates on the work being carried out and outlines the progress achieved prior to the deployment of the handbook in European national emergency response organizations, which are in the process of testing and evaluating the material through targeted emergency response exercises.
The end of this paper includes some remarks on the challenges that need to be dealt with in order to achieve a sustainable development of what has been achieved through the lifetime of this project.

KEYWORDS:, Triage, monitoring, medical treatment counter terror, Malevolent acts

1.- Introduction

European national emergency response plans have long been focused on accidents at nuclear power plants. This has resulted in well developed, reviewed and exercised plans taking place at these fixed facilities. The evolution of nuclear emergency planning has led to the refinement of response plans away from fixed nuclear sites, such as the accidents involving the transport of radioactive material. The magnitude of these events whilst generally smaller due to the smaller quantities of radioactive material involved pose there their own problems due to the difficulties associated with prior planning for location specific factors, high density populations, etc. More recently, the possible threats by disaffected groups have shifted the focus to being prepared for malevolent use of radiation that are aimed at creating disruption and panic in the society.
Scenarios that fall into this malevolent category host a whole range of issues that require consideration. Historically, the terms accident and emergency have been used interchangeably. Unfortunately, the political landscape has changed to such an extent that in an emergency situation the question "mistake or malicious" has to be asked. Whilst this may not render the actual response at an individual or operational level any differently, there are aspects in the strategic and tactical response that may vary. A whole host of questions are raised and need to be answered, in part to ensure the safety of the emergency responders.

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In order to provide practical guidance for responders in the event of the malevolent use of radiation a programme of work has started to develop the Triage, Monitoring and Treatment Handbook (TMT Handbook). This paper reviews the progress on the first stage of the handbook and highlights some of the key aspects identified when trying to co-ordinate an international response to these events and provide an insight into the European approach to these issues. Finally, this paper provides an overview of the TMT Handbook project, while specific aspects such as: triage, monitoring and medical treatment are dealt with in separate contributions.

2.- Review existing guidance and research

There are a number of recent internationally recognised publications that have started to address some of the issues raised in responding to malevolent use of radiation, notably, ICRP Publication 96 [1], protecting people against radiation in the event of a radiological attack. This document focuses protection criteria for responders and the public. There is a brief foray into Medical intervention. The report does states that it does not make recommendations for medical treatments of radiation injuries although there is are some descriptions of therapies in the Annexes.However this is not in the form of an operational manual.
NCRP [2] provides an excellent review of the consequences to resulting from the use of improvised nuclear devices (IND) and other malevolent uses of radiation. This assists in providing bounding estimates regarding the scenario and effects but again it is beyond the remit of the review to consider the triage and treatment of people affected.
A number of IAEA publications [3, 4, 5, 6] including the recently published, advice to first responders [7] and the updated EPR-Medical [8] provides useful guidance on the generic treatment options available.
In addition to the published articles in journals on specific medical treatments [9, 10] there are a host of generic response guidance and protocols produced at a national level.

EC Research Programmes

There are a number of research programmes currently being funded within the EC this includes:

- Coordination Action for Radiation Dosimetry (CONRAD)
- Treatment Initiatives after Radiological Accidents (TIARA)

The UK Health Protection Agency has a task in the EU/EURADOS-sponsored CONRAD project which aims to collect information on emergency personal monitoring methodologies in EU countries. This work will be extended to collect information on the strategic response. Links with this project will provide effective contacts with organisations that have responsibilities in this field, and will be an important source of information for the TMT Handbook.
The TIARA project focuses on provision of guidance on issues relating to efficacy of treatment. As its starting point, it assumes that monitoring measurements on people in the immediate phase have been completed, and in particular that bioassay results (i.e. whole body, urine or faecal measurements) are available. Furthermore, it is concerned only with scenarios that could result in levels of internal contamination that would justify treatment to remove radioactive material from the body (decorporation) and, perhaps most importantly, TIARA is firmly based in Research and development; specifically, the development of a dosimetric method to allow the identification of people who may require decorporation treatment, the review of scientific developments in research into new treatments, and the development of a new chelating agent for uranium.
It is therefore easy to distinguish the differences between the TIARA programme and the TMT handbook, notably, the TMT Handbook will:

- provide practicable guidelines on the management of people from the beginning of an incident involving the malevolent use of radiation or radioactive material
- consider scenarios that involve external irradiation, as well as those involving releases of radioactive material that could result in both external and internal contamination
- make use of existing knowledge and practice to address the specific problems raised by the potential malevolent use of radiation or radioactive material

3.- The need

Due to the focus on "accidental" releases much of the guidance is specifically focussed towards these issues. The "malicious" event is one that is relatively new to our consciousness and therefore there is relatively little established guidance available specific to this situation. Whilst there are numerous overlaps with accidental situations in terms of the public protection a number of specific issues need to be considered,

- How do you ensure the effective triage of members of the public exposed to radiation or radioactive materials?
- What are the best means of monitoring members of the public, what strategies are adopted at a national level and what resources are available?
- Which treatments options are available and offer the most effective response?

This is of particularly significance for malevolent event due to the potential for large numbers of people to be, or suspected to be, exposed. It is also apparent that whilst national plans have been developed to respond to these issues these have been, on the whole, developed in isolation. Any significant event could affect more than one country due to transboundary migration of contaminants, migration of people, or transfer of goods.
Generic guidance on this topic has been published by national and international organisations. They are, however, not operational documents to be directly used in emergency situations. So, whilst depending on the scenario, the number of affected people can vary from a few victims to mass casualties; the radiation exposure can range from very low to substantial, possibly combined with conventional injuries. There is a need to develop practicable tools for the adequate response to such acts and more specifically to address European guidelines for triage, monitoring and treatment of exposed people. The aim of this project is to try and develop consistent guidance on the response to the malevolent use of radiation that affects the public.

4.- Aims and objectives

The TMT Handbook aims to strengthen the European ability to efficiently respond to malevolent acts in terms of protecting and treating exposed people. Part of the Handbook is also devoted to public information and communication issues which would contribute to public reassurance in emergency situations.

The objective of this project is to develop a harmonised approach for the effective and timely monitoring and treatment of populations exposed as a result of the malevolent use of radiation and radioactive material by utilising existent existing national and international guidelines in this manner. This is to:

1. ensure the protection of the public;
2. develop a common and consistent response and driving best practice, and
3. add value to former developments of national and European programmes.

The Handbook will aim to harmonise the approaches to handling malevolent acts across Europe. This harmonisation will have an added value on the public confidence in authorities since differing approaches in neighbouring countries could lead to public confusion and mistrust.

5.- Consortium

The Handbook has been drafted by European and international experts and circulated to emergency response institutions in Europe that would play a part of in the handling of malevolent acts using radioactive material. The institutions were given a consultation time with encouragement to test the

draft Handbook in national exercises. A workshop will allow feedback from these end users on the content, structure and usefulness of the Handbook before a final version is produced.
In order to achieve these objectives a project consortium has been drawn together including, Belgian Nuclear Research Centre, the Norwegian Radiation Protection Authority, Radiation and Nuclear Safety Authority of Finland, the UK Health Protection Agency, the Central Laboratory for Radiological Protection of Poland and the World Health Organisation. Enviros Consulting is acting as the technical secretariat for the project.

Belgian Nuclear Research Centre (SCK•CEN)
SCK•CEN, is the Belgian Nuclear Research Centre being a foundation of public utility under the tutorial of the Belgian Federal Minister in charge of energy. The statutory mission gives the priority to research on problems of societal concern like safety of nuclear installations, Radiation protection, safe treatment and disposal of radioactive waste, fight against uncontrolled proliferation of fissile materials, education and training, etc.
In order to perform its research programme and to provide its services to industry and third parties, SCK•CEN collaborates with several nuclear facilities, as well as emphasising its educational and training programmes such as coordinating the Belgian and initiated the European Nuclear Engineering Network, International School for Radiological Protection. SCK•CEN has a long tradition in the organisation of off site nuclear emergency response training courses, which in the past were sponsored by the European Commission Research and Training Programme, and thus plays a leading role in assisting the government in nuclear and radiological emergency response related issues.

Norwegian Radiation Protection Authority (NRPA)
NRPA is the Norwegian authority on radiation protection and emergency response. NRPA has been involved in numerous research projects and has good experience in arranging consensus meetings and conferences and will use their expertise in this field to ensure a good communication with end users throughout the project.

NRPA is chairing the National Competent Authorities' Coordination Group (NCACG), whose main role is to cooperate with the member states, to ensure successful implementation of the long term *International Action Plan for Strengthening the International Preparedness and Response System for Nuclear and Radiological Emergencies.*

Enviros Consulting Limited
Enviros is one of the UK's largest environmental consultancies and is highly respected on an international basis for environmental consultancy and software development. Enviros specialises in research development support, site characterisations and remediation, waste management, environmental impacts assessment, planning and permitting and specialist modelling and software services.
Enviros provides consultancy and support services in the nuclear sector to clients in the UK, Europe, Former Soviet Union, Japan and North America. Enviros' expertise is broad covering radiological emergency planning and response, radioactive waste safety assessment and regulatory support services. The Enviros team has been contributing to R&D in European projects and has considerable experience in providing technical secretariat services to a wide range of projects including regulatory support and European funded projects.
The Enviros team includes technical experts in radiation protection, radiation monitoring, emergency planning and response. These skills are augmented by strong project management, training and workshop facilitation skills.

Health Protection Agency (HPA)
The role of the Health Protection Agency (HPA) is to provide an integrated approach to protecting UK public health through the provision of support and advice to the National Health Service, local authorities, emergency services and the Department of Health. Advising on the protection of people in radiological emergencies is a fundamental part of the responsibilities of the Radiation Protection

Division of the Health Protection Agency (HPA-RPD, formerly the National Radiological Protection Board (NRPB)).
HPA is responsible for the coordination of monitoring (both personal and environmental) in the UK following any accidental or deliberate release of radionuclides, and also has a significant operational capability for both environmental and personal monitoring. It plays a leading role in national emergency exercises and would play a major role in the national response to such an event.

World Health Organisation (WHO)
The World Health Organization is the United Nations specialized agency for health. The Radiation and Environmental Health Unit (RAD) of the Sustainable Development and Healthy Environments Cluster is involved in several dey activities pertinent toth project, notably the coordination of the global RAD develops, coordinates and disseminates science-based information and guidelines on all issues related to radiation emergency medicine.
RAD is the WHO focal point for the global system of the international response to nuclear and radiological accidents. This is implemented via 32 medical institutions members of REMPAN network, the bulk of which are located in the EU REMPAN provides consultation and advice on preparedness and response to radiation emergencies to 192 Member States of the WHO assists in treatment of victims, long-term follow-up, research coordination, education and training.

Nuclear and Radiation Safety Authority (STUK)
STUK is a Finnish public agency, whose main objective is to prevent and limit the harmful effects of radiation. STUK is a safety authority for the use of nuclear energy and radiation. Emergency preparedness arrangements have been established within STUK for radiological and nuclear emergencies. Maintaining an effective preparedness for field and laboratory measurements in order to cope with abnormal radiation situations is an important part of research activities. Mobile systems as well as fixed stations for radiation monitoring are developed. In recent years STUK has successfully participated in tens of research projects financed by the European Union.

Central Laboratory Radiological Protection (CLRP)
The statutory responsibility of Central Laboratory for Radiological Protection (CLRP) of Poland is protection of general population, occupationally exposed persons, and the environment against the hazards of ionizing radiation. CLRP has been particularly involved in the national monitoring of radioactive contamination in foodstuffs and environmental components, offering assistance in a radiological emergency or nuclear accident, and supporting the countermeasures against illegal trafficking in nuclear and radioactive materials.
CLRP participated in several national and international research projects, prime among them were those sponsored by the European Union, by bilateral agreements between CLRP and Institute of Transuranium Elements in Karlsruhe (ITU), Germany. With the assistance of the ITU, under the PECO project (Pays Europe Centrale Orientale), CLRP has elaborated and implemented the handbook for the response to illicit trafficking, or inadvertent movement of nuclear and radioactive materials in Poland.

7.- Results

At this stage it is envisaged that the principles developed in this project will certainly contribute to the core of international practices and protocols applicable beyond the EU. This project also provides excellent opportunity for project outcomes to contribute to international standards and guidelines on emergency response.
One of the initial stages of the project was the development of bounding scenarios from current and existing work. These are to identify the range of scenarios to which the Handbook can be used and the reasonable limits that can be applied. We also carried out a strategic review of response capability of European countries to the threat of the malevolent use of radiation. This task was co-ordinated by the Health Protection Agency, and many of their key staff were deployed in a real life situation regarding the malevolent use of Polonium-210 to poison the former Russian citizen, Mr Litvenenko. There were

of course many lessons learnt from this incident, which still are in the process of being studied and applied to the TMT handbook.
In trying to define the end-users of the handbook Emergency Response Organisations were contacted with specific functions to plan, co-ordinate and execute the national, regional and/or local public-health and medical response for actual, or potential events of malevolent use of radiation. In addition, there was a need to clearly define an event that triggers the use of the handbook. Hence, this handbook should be used where a possible malevolent event has occurred and use of radiation or radioactive contamination has either been confirmed or cannot be ruled out.

Draft Structure
A preliminary structure was drafted and agreed upon, and follows in a time critical chronological order. Whenever possible the plan was to make a user friendly format with flow diagrams to guide the users through the appropriate stages with checklists and action plans to ensure the necessary steps are included. These sections are augmented with more detailed guidance and notes in technical appendices.

Information dissemination
The consultation of emergency response institutions is a vital part of the project. Getting feedback on the content, structure and usefulness of the Handbook is imperative for producing a useful guidance. Hard copies of the Handbook are to be published by the European Commission. Electronic copies of the final Handbook will be available free of charge on the project's web page. The web page is also be open to the public and important findings and reports will be posted here during the lifetime of the project.
Training is envisaged towards the end of the project. The training will be for both European participants and international participants through the WHO REMPAN network.
It is believed that the consultation, workshop to be held in December 2008 in Lillehammer, Norway and training course scheduled for February 2009 will raise awareness of the topic and the Handbook in many countries across Europe and also beyond.

8.- Challenges and next steps

The key challenges for this project are to:

- develop a useful operational handbook that is applicable at a strategic, tactical and operational level across a number of countries. Ensuring a sufficient level of detail to be useful without being overly prescriptive that might result in its exclusion from use in some areas.
- keep up with the rapid developments in this field given the rapid developments that are taking place in a number of relevant disciplines. Since starting this project a number of publications have become available. However, to a certain extent this reinforces the need for a co-ordinated and harmonised approach as advocated by the TMT approach.
- ensure the sustainable development of this handbook, which should go beyond the lifespan of this project.

The next steps are:

- the finalisation of the handbook considering the feedback provided by European emergency response organisations,
- the completion of a training course to "to train the trainers", which will be held in February 2009.
- to ensure that knowledge is maintained through e.g. the WHO REMPAN centres and that the necessary steps are undertaken to organise training activities.

An important aspect that was not foreseen in this project, but has been identified, is the fact that in order to facilitate its dissemination and use the handbook would have to be translated into other European languages.

9.- Acknowledgements

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Test of active personal dosimeters for interventional radiology in realistic radiation fields

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Abstract. In Interventional radiology, the medical staff stands close to the patient during his exposure to X-rays. Consequently, they can be exposed to relatively high doses due to radiation scattered by the patient and the medical equipment. Contrary to the passive dosemeters which assess the doses a posteriori, APDs are able to warn the medical staff when doses and/or dose rates exceed pre-defined radiation protection limits. At interventional radiology workplaces, APDs must be able to measure low-energy photons (10-120 keV) and pulsed radiations with relatively high instantaneous dose rates delivered by medical X-rays generators. Six ADP models, considered as suitable for application in interventional radiology on the basis of the results of a previous comparison jointly organised by EURADOS and IAEA, were selected to carry out a new comparison in 2007. This included radiation fields able to mimic the scattered and pulsed X-ray radiation fields met at workplace in hospitals. Irradiations took place at CEA-LIST LNHB (Saclay, France) and IRSN (Fontenay-aux-Roses, France). This paper describes the irradiation assemblies both for realistic and classic calibration facilities. The reference values of the personal dose equivalent, $H_p(10)$, were determined through measurements and simulations to calculate the response of the APDs. The results shed light on the ability of APDs to measure correctly the doses, when used in the specific low-energy spectra and dose rates of pulsed X-rays encountered in interventional radiology.

KEYWORDS: active personal dosemeters; intercomparison; interventional radiology; X-rays.

1. Introduction

The evaluation of active personal dosemeters (APDs) in interventional radiology was performed by work package 7 (Radiation protection dosimetry of medical staff) of the CONRAD project, which is a Coordination Action supported by the European Commission within its 6th Framework Program. The objective of WP7 was to promote and co-ordinate research activities for the assessment of occupational exposure to staff at workplaces in therapeutic and diagnostic radiology and nuclear medicine.

APDs are used for the monitoring of occupational doses in many applications of ionising radiation. In interventional radiology, the possibility to assess the dose in real time is particularly interesting since operators are liable to receive relatively high doses while standing close to the primary radiation field and being exposed to radiation scattered by the patient. For the adequate dosimetry of these scattered photons, APDs should be able to measure low-energy (10-120 keV) and pulsed radiation with relatively high instantaneous dose rates. Unfortunately, the current APDs are not always adequate. This problem was clearly highlighted during an international intercomparison organised by EURADOS and IAEA [1].
An evaluation of the behaviour of six APD models that, according to the manufacturers and the IAEA (2007) results, were considered suitable for application in interventional radiology was performed through an intercomparison. Its aim was the identification of the APDs which provide a correct response when used in the specific low-energy spectra and dose rates of pulsed X-rays encountered in

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interventional radiology. The results of this intercomparison are not the scope of this paper, they can be found in *Clairand, et al., 2008* [2].

This paper describes the irradiation assemblies that were set up both for realistic and classic calibration facilities. It focuses on the reference values of the personal dose equivalent, $H_p(10)$, which were determined through measurements and simulations in order to be able to calculate the response of the different APDs.

2. Materials and method

2.1 Design of a realistic calibration field for interventional radiology

In interventional radiology the X-ray tube is most of the time located under the patient and the radiologist stands at his side, often at the level of the hip. Thus, the doctor is exposed to the radiation scattered by the patient. Sometimes, collective protection equipments (e.g. screens, table curtains) are available and can be used to partly reduce the dose received by the doctor. The image intensifier is located symmetrically to the X-ray tube with respect to the patient (see figure 1).

The idea was to propose an irradiation assembly which could be set up easily in any primary or secondary calibration laboratory. From a real workplace situation few simplifications were introduced. First, as it was found that the image intensifier and the patient table do not contribute significantly to the scattered radiation field at the doctor's level, they were not included, however the attenuation of the table was included in the total filtration considered. Secondly, the patient was replaced by an ISO water slab phantom [3]. The surgeon was represented by an ISO slab phantom on which the dosemeters were irradiated. On figure 2 the irradiation configuration is shown. It can be seen that the doctor-phantom was shifted from the level of the hip of the patient to the side face of the patient-phantom. Calculations showed that the energy distributions at both locations are similar but the total fluence is multiplied by a factor of 3.6 when moving the calibration point. Detailed results on the design of the calibration field can be found in *Bordy et al., 2008* [4].

2.2 Description of the facilities and intercomparison configuration

The intercomparison of the APDs was performed with pulsed and continuous X-ray beams, available respectively at the Laboratoire National Henri Becquerel (LNHB) at CEA-LIST, the French National Metrology Laboratory for ionizing radiation in Saclay, and at a metrology laboratory of the Institute of Radiological Protection and Nuclear Safety (IRSN) in Fontenay-aux-Roses. Both laboratories are accredited according to the ISO standard 17025 [5]. The diagnostic pulsed X-ray beam was generated with a MPH65 (GEMS) medical X-ray unit designed to generate only one pulse at a time. The continuous X-ray beam was generated with a 100 kV (Philips) X-ray unit.

A configuration close to clinical practice was considered: peak tube voltage and filtration of 70 kVp and (4.5 mm Al + 0.2 mm Cu), respectively. Because collimation devices did not have the same geometry (circular and square for continuous and pulsed facilities, respectively), the collimator openings were chosen such as the areas of both (non-scattered) beam cross sections were the same (around 290 cm² at 95 cm from the source). The distances between the different equipment and the phantoms were taken from information gathered from the practitioners.

Figure 1: Side and top views of the workplace configuration.

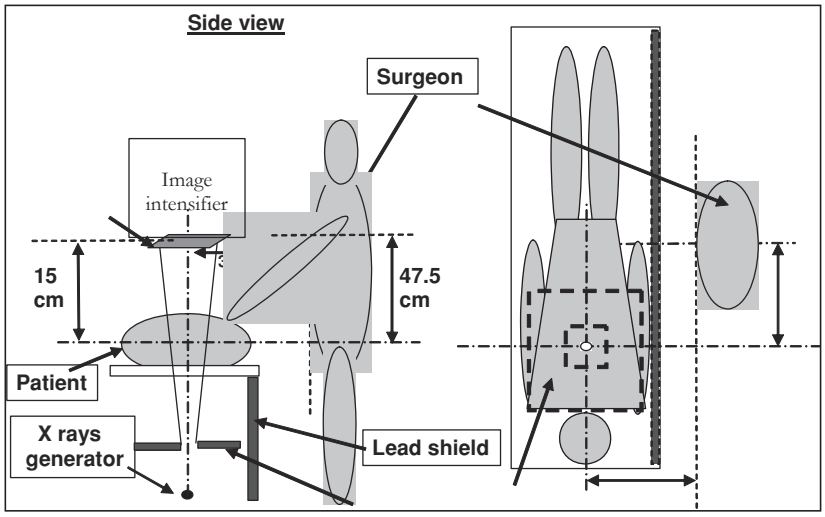
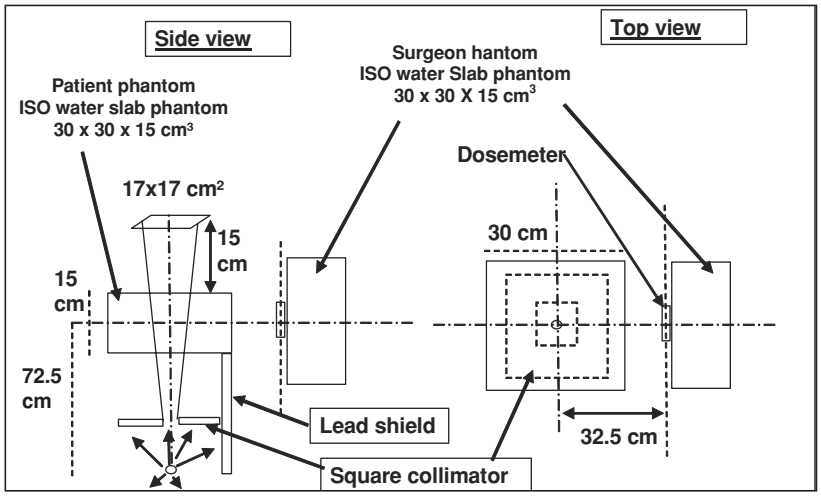


Figure 2: Side and top view of the simplified configuration used for the intercomparison.



For the pulsed facility, a pulse width of 100 ms was used. It has to be noticed that clinical pulse widths can vary within few ms to few hundreds ms depending on the examination, X-ray installation and practice. The patient phantom's front wall was positioned at 65 cm from the source. APDs were irradiated one by one at the centre of the radiologist phantom's front wall. The centre of the radiologist phantom was positioned at the same level as the centre of the patient phantom (72.5 cm from the source). The centre of the tested APD was shifted by 32.5 cm in the normal direction with respect to the beam axis. A lead shield was used to remove the X-ray component produced through scattering in the tube housing and irradiating the radiologist phantom (and the dosemeter). Without the shield, this scatter component appeared to increase the dose rate by more than 30% at the dosemeter position and it was shown that it was due to scattering in the filters.

2.3 Reference quantities

It was necessary to determine a reference value in terms of $H_p(10)$ in the scattered beam at the position of the APD. First, free in air kerma K_a was measured with a calibrated cavity chamber at the point of test in the scattered beam. At this point, K_a rates were found equal to 3.03 mGy.h^{-1} and 3.20 µGy.pulse^{-1} for the continuous and pulsed installations, respectively. The overall uncertainties on K_a were estimated to 1.2 % and 1.0 % (k = 1) for the continuous and pulsed installations, respectively. Next, a conversion coefficient was needed to convert air kerma into $H_p(10)$. The published conversion coefficients from K_a to $H_p(10)$ [6] are defined for parallel, expanded radiation fields, which are not representative for the considered energy and angular distributions in the scattered field used for this intercomparison. Thus, Monte Carlo calculations were performed for the determination of $H_p(10)/K_a$ for the specific scattered beam spectrum. Different codes were used: MCNP4C [7], MCNP5 [8], MCNPX [9] and Penelope 2006 [10].

K_a was calculated in a 1 cm radius sphere filled with air centered at the test point, in the absence of the radiologist phantom. $H_p(10)$ was calculated as the dose absorbed in a cell centered at the test point and positioned at 10 mm within the 30x30x15 cm³ ICRU slab phantom. The lead shield was introduced as well in the model, with 65 cm height and covering the whole patient phantom width (30 cm).

The source filtered 70 kVp X-ray spectrum used in the Monte Carlo simulations was calculated with the deterministic software XCOMP-5 [11], taking into account the filtration (4.5 mm Al + 0.2 mm Cu) and the different tungsten anode angles. This means that filters were not explicitly introduced in the simulations. However, the XCOMP-5 filtered spectrum was checked against an MCNPX calculation (figure 3) in which the source unfiltered spectrum (calculated by XCOMP-5) was filtered by 4.5 mm Al and 0.2 mm Cu. It can be seen that the agreement is very good and that the source spectrum ranges from around 25 keV up to 70 keV. From this comparison it was also observed that less than 10% of the collimated source flux is transmitted through the filters. From the source, considered as a point-like isotropic X-ray emitter, collimation was taken into account by restricting the emission angles to a cone with appropriate opening solid angle. In the instance of the pulsed installation, for which the collimator was a square, an additional perfect square collimator (null importance for photons) was defined. All tricks previously mentioned (not explicitly defining filters and collimators), although strongly simplifying reality, allowed to greatly speed-up calculations.

Only photons were transported (kerma approximation: secondary electrons generated by photon interaction deposit their energy locally), detailed photon physics treatment, as defined in MCNP4C manual, was considered and all photon physical processes taking place at these energies, i.e. fluorescence emission, photoelectric absorption, incoherent (Compton) and coherent (Thomson) scattering, were taken into account.

Absorbed dose was calculated by different techniques, either by fluence tallies (F2, F4, F5 in MCNP) multiplied by appropriate ICRU conversion coefficients, or dose tally (F6 in MCNP), or energy deposition tally (*F8 in MCNP). For the fluence tallies, the dosimetric quantities (either K_a or $H_p(10)$, as appropriate) were calculated by folding the fluence with the conversion coefficient taken from ICRU report 57 [5] according to the following equations:

$$K_a = \int_E \phi_E \left[\frac{K_a}{\phi}\right](E)\,dE \qquad H_p(10) = \int_E \phi_E \left[\frac{H_{p,slab}(10,0°)}{\phi}\right](E)\,dE$$

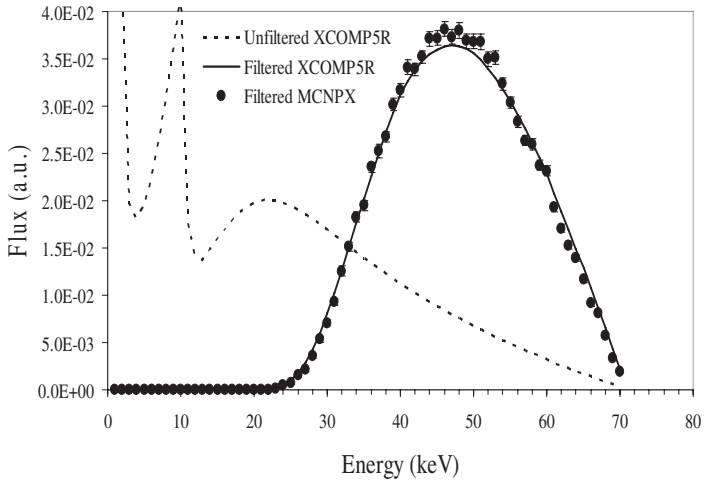
where the ratios K_a/ϕ and $H_{p,slab}(10,0°)/\phi$ are the appropriate conversion coefficients.

To determine the reference $H_p(10)_{ref}$ value, $H_p(10)/K_a$ calculated as previously explained was multiplied by the measured reference value in terms of air kerma $K_{a,ref}$

$$H_p(10)_{ref} = {}^{H_p(10)}\!/_{K_{air}} \times K_{air,ref}$$

For the continuous beam, the reference K_a at the test point was 150 µGy after 178 s of irradiation and for the pulsed beam, the reference K_a at the test point was 80 µGy after 25 pulses.

Figure 3: Unfiltered and filtered by 4.5 mm Al and 0.2 mm Cu 70 kVp X-ray spectra, on an arbitrary unit, calculated with XCOMP-5 [10] for a tungsten anode with angle 20°; the filtered spectrum is compared to an MCNPX calculation with an unfiltered source spectrum, filtered by 4.5 mm Al and 0.2 mm Cu.



3. Results

Three different laboratories performed calculations to define the appropriate conversion coefficient from K_a to $H_p(10)$ for the considered energy spectrum in the scattered field: CEA-LIST (LNHB), IRSN and SCK•CEN. In table 1, all calculation results are summarized.

A study on the angular dependence of the scattered radiation was performed, calculating the spectra for different angles with respect to the normal axis of the radiologist-phantom and considering the $H_p(10, \alpha)/H_p(10, 0°)$ coefficients in ICRU Report 57 [6]. We could conclude, however, that this study changed the conversion coefficient $H_p(10)/K_a$ by less than 2%.

The $H_p(10)/K_a$ conversion coefficient that we used for the intercomparison was 1.40 $Sv.Gy^{-1}$, i.e. a mean value between the estimates from the different codes using dose (tally F6 in MCNP) or energy deposition (tally *F8 in MCNP) tallies. Taking into account both Monte Carlo statistical (type A) errors and scattering of the different results around the mean value, that accounts for type B errors, the uncertainty on the $H_p(10)/K_a$ conversion coefficient could be estimated to 1.2 % (k = 1). However, since all calculation results were obtained with similar and simplified models for the radiation source and the geometry, an additional type B uncertainty on the conversion coefficient was assumed, leading to a total relative uncertainty estimated to 3 % (k = 1).
Thus, the conversion coefficient was taken as:

$$\frac{H_p(10)}{K_{air}} = 1.40\ Sv.Gy^{-1} \pm 3\%$$

4. Discussion

The $H_p(10)/K_a$ conversion coefficient that we used for this intercomparison was 1.40 $Sv.Gy^{-1}$, i.e. a mean value between the estimates from the different codes using dose (tally F6 in MCNP) or energy deposition (tally *F8 in MCNP) tallies. It is interesting to notice that if K_a and $H_p(10)$ were calculated through fluence spectrum (tallies F2, F4 or F5 in MCNP) folded with the energy-dependent ICRU report 57 [6] conversion coefficients at 0°, a value around 1.5 $Sv.Gy^{-1}$ was obtained, i.e. 7 % larger than 1.40 $Sv.Gy^{-1}$. This is due to the fact that ICRU hypotheses were not fulfilled for the investigated configuration, i.e. (1) the scattered X-ray beam incident on the radiologist-phantom was not parallel, though angular effects were shown to be small and (2) the radiologist-phantom was not homogeneously (and not completely) irradiated, thus leading to a reduced contribution of backscattered photons. The latter point provides the principal explanation of the different conversion coefficients between the two calculation methods. Therefore, ICRU report 57 conversion coefficients should not be used in combination with the fluence spectra calculated for this study.

Table 1: Summary of all calculation results of $H_p(10)/K_a$ for CEA-LIST, IRSN and SCK•CEN

X 10^{-6} (pGy/history or pSv/history)		K_a			$H_p(10)$			$H_p(10)/K_a$		
		F5	F6	*F8	F5	F6	*F8	F5	F6	*F8
CEA-LIST	MCNP4C - lib02p square field	4.64 (0.2%)	4.40 (0.3%)	4.42 (1.2%)	6.97 (0.2%)	6.31 (0.6%)	6.33 (3.0%)	1.50	1.43	1.43
	MCNP5 - lib04p square field	4.29 (0.2%)	4.38 (0.2%)	4.35 (0.7%)	6.44 (0.2%)	6.23 (0.4%)	6.16 (1.9%)	1.50	1.42	1.42
	Penelope2006 square field		4.87 (2.6%)			6.77 (0.5%)			1.39	
IRSN	MCNPx2.5f - lib04p circular field		4.83 (0.7%)			6.75 (0.5%)			1.40	
	MCNPx2.5f - lib04p square field		4.85 (0.7%)			6.80 (0.6%)			1.40	
SCK•CEN	MCNPx2.5.0 – lib04p square field	4.67 (0.04%)	4.93 (0.7%)	4.93 (1.0%)	7.06 (0.03%)	6.96 (0.6%)	6.91 (0.9%)	1.51	1.41	1.40

As mentioned before, in the experiments an additional lead shield was used to attenuate most of the scattered radiation produced in the filters. These filters are inserted after the collimation system. When calculations are performed with and without this lead shield, the K_a ratio at the test point between both configurations without and with lead shield is close to unity (1.06). However, when K_a at the test point was measured with and without lead shield, a ratio of 1.30 and 1.94 was obtained at the pulsed and continuous installations, respectively. These differences between both experimental facilities and between measurements and calculations led us assume that some of the experimental conditions are not well reproduced in the calculation models. When the filtration is explicitly taken into account in the calculation model, starting from an unfiltered spectrum, filtered in the model by 4.5 mm Al + 0.2 mm Cu (figure 3), a K_a ratio without and with lead shield is found to be 2.45 (for the continuous installation), which is closer to the measurements.

It was also observed that there was a difference in position of the lead shield between both installations, but it was investigated that this factor could not have an impact larger than 5 % on the resulted measurements.

To complete the investigation of the differences between both experimental installations and between experiments and calculations, the sensitivity of the results with respect to the knowledge we have about the X-ray tube has been investigated. These results can be found in more detail in *Struelens et al, 2008* [12].

5. Conclusions

Active personal dosemeters measure dose equivalents and dose equivalent rates in real time and provide adjustable audible alarms. They are efficient tools to help reducing doses by optimising practices as well as collective and individual protection. They are of particular interest in situations with possible high doses and/or dose rates as in the medical field. During interventional procedures the staff is standing close to the primary X-ray radiation field and is exposed to radiation scattered by the patient. In these situations, APDs should accurately respond to low energy (10-120 keV) and pulsed photon fields.

An intercomparison of selected APDs was carried out in continuous and pulsed radiation fields similar to the field characteristics met at interventional medical workplaces. This paper has described the preparatory work for such an intercomparison, such as the design and the implementation of a realistic calibration facility for these kinds of procedures and the calculations necessary to determine the reference dose equivalent value $H_p(10)$.

A conversion coefficient $H_p(10)/K_a$ was calculated of 1.40 $Sv.Gy^{-1}$ ± 3% for the specific scattered radiation field used for the intercomparison.

Differences were observed between measurements in the two experimental laboratories and between measurements and calculations. It was concluded that the observed differences come from the assumptions made about the geometry of the X-ray tubes and that the simulation models of the X-ray tubes might be too simple, particularly when calculations and measurements are performed in the scattered beam. We should also bare in mind, as there is no absolute Monte Carlo computer code, it is normal to find some discrepancies between experiments and calculations. This lay emphasis on the need of accurate calibration of the transfer dosemeters used to measure the dose rate at the point of test.

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Identification and characterization of NORM industries in Belgium

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Abstract. An overview of the NORM issue in the Belgium industry is given, mainly based on a study on behalf of ONDRAF/NIRAS, the Belgian agency for radioactive waste. The phosphate industry, which was identified as the main source of enhanced natural radioactivity, is mainly located in Flanders, the northern part of Belgium. The five Flemish phosphate plants handled, from 1920 to 2006, 60 Mton of phosphate ore containing 72 TBq of uranium-238 (radium-226) and 3.5 TBq of thorium-232. This resulted in a vast legacy of 500 ha of contaminated sites. In the non-ferro industry high activity-concentrations of the thorium decay series were identified with cassiterite (tin ore). Zircon sands with high uranium concentrations are applied for the production of precision casting molds. Almost every industry with a large turnover of materials has some problems with NORM, because of the selective concentration of certain radionuclides in by-products, residues or product streams. Examples of a blast furnace and a coal-fired power plant are given. In these cases the natural radioactivity is concentrated in blast furnace slag or fly ash, both of which are used as input material in the cement industry. The extraction and purification of ground water was also identified as a potential source for generating NORM sludges. Finally, ample remains from past NORM practices exist. A number of historical sites, including a former mining area of alum shale in the valley of the Meuse, several coal mining sites, a coltan processing site in Ghent and a radium facility in Olen were contaminated before present standards of radiological protection were developed.

NORM, enhanced natural radioactivity, Belgium, non-nuclear industry, phosphate industry, steel industry, coal-fired power plant, radium

1. Overview of NORM in the Belgian industry

Problems with naturally occurring radioactive materials (NORM) are not limited to the processing of raw materials containing high specific activities of the uranium or thorium decay series. In fact, almost every industry with a large turnover of materials has some problems with NORM, because of the selective concentration of certain radionuclides in by-products, residues or product streams. A recent study, on behalf of ONDRAF/NIRAS, the Belgian agency for radioactive waste, identified ten industries within Belgium where processing of NORM can cause environmental contamination, waste problems or an increased exposure of workers and members of the public [1]:

- phosphate industry;
- iron and steel industry;
- coal-fired power plants;
- non-ferro industry;
- zircon sand and refractory materials;
- cement production;
- use of thorium compounds;
- extraction and purification of drinking water;
- former mining area of alum shale;
- slag heaps from coal mining;

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Also other industrial activities in Belgium, like the titanium dioxide pigment production and the oil and gas industry were identified and there relevance for generating by-products or residues with enhanced natural radioactivity was checked.

A wide range of exposure scenarios apply to the different NORM industries. Even within the same industry, the exposure of workers and the local population is very diverse. The phosphate industry, which is the main source of enhanced natural radioactivity in Belgium, is an excellent example to illustrate this point [2]. The nature of the NORM problems differs widely from one phosphate plant to another and simple protective measures are in most cases sufficient to reduce the occupational and public exposures. That's why the European Legislation on work activities is kept deliberately flexible [3]. Furthermore there is a vast legacy from past NORM practices. Most of the historical sites were contaminated before present standards of radiological protection were developed. An overview of the NORM legacy and the most important NORM industries in Belgium will be given hereafter. Despite the inquiry, the survey is far from being complete and has to be seen as a start for carrying out more detailed studies.

2. Phosphate industry

2.1 Introduction

The amount and the composition of the natural radioactivity in phosphate ores depend on their origin. Marine (or sedimentary) phosphate ores show radionuclide concentrations from the uranium decay series that are 10 to 100 times higher than the typical values of the Belgian soil. Ores of magmatic origin contain less of the uranium and more of the thorium decay series. The natural radioactivity of phosphate ores used in Belgium is shown in table 1. Most of the information was collected on the request of the Flemish Environment Agency (VMM) [4].

Table 1: Range of activity concentrations of the natural uranium and thorium decay series in phosphate ores used in Belgium. The typical range for Belgian soil is also indicated.

Origin	U-238 (Ra-226) Bq/kg	Th-232 Bq/kg
Marine phosphate ore Morocco Florida (USA)	500 - 5000 1200 - 1600 1500 - 2000	10 - 100 10 - 30 20 - 60
Magmatic phosphate ore Kola (Russia) Palfos (South Africa)	30 - 150 30 - 60 150	20 - 500 60 - 100 500
Belgian soil	10 - 50	10 - 50

The natural radioactivity of phosphate rock is only an 'annoying' property that is mostly combined with the presence of heavy metals. The production process determines where the radioactivity of the ores turns up. The acidulation of phosphate rock with sulfuric acid (H_2SO_4) is worldwide the most used method. The bulk of the radium-226 activity turns up in the insoluble by-product calciumsulphate or (phospho)gypsum ($CaSO_4$). Five plants in Belgium are using, or have used, this production process:

- UCB, Ostend (from 1953 till 1987);
- Prayon Rupel, Puurs (from 1963 till 1992 when the basic phosphoric acid production facility moved to Morocco);
- Nilefos (former Rhodia Chemie), Zelzate (from 1925 till now);
- BASF, Antwerp (from 1967 till 1993);
- Prayon, Engis (from 1973 till now).

Tessenderlo Chemie produces dicalciumphosphate through acidulation with hydrochloric acid (HCl). The main by-product is sludge of calciumfluoride (CaF_2). Two thirds of the radium went into the

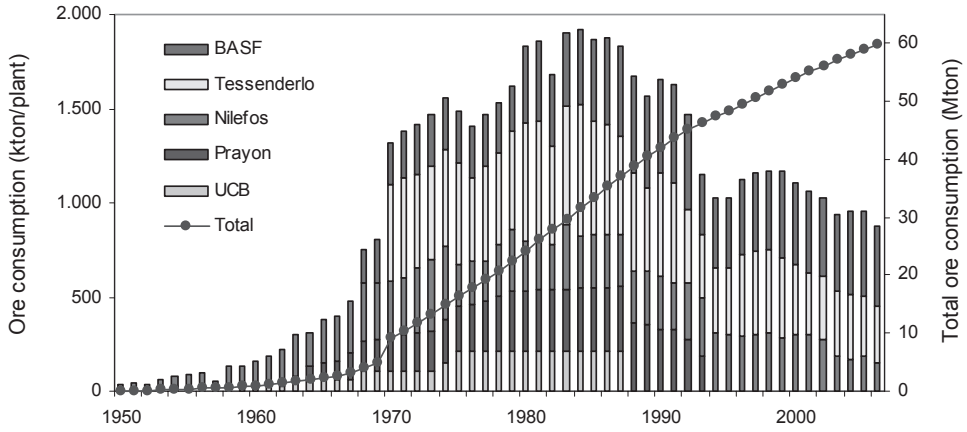
solution and was evacuated with the effluent waters in two small rivers: the Grote Laak and the Winterbeek. In 1991 a decontamination stage, based on dissolved barium salts, was put into operation, decreasing the radium contents of the effluent waters by an order of magnitude, at the expense of increasing the radium contents of the sludge to about 10 kBq/kg. The two production units of Tessenderlo Chemie are located in the neighboring villages of Tessenderlo (from 1920 till 1995) and Ham (from 1931 till now).

BASF Antwerp uses since 1980 also nitric acid (HNO_3) as dissolution agent. Here no substantial waste flows are being produced. This implies that the radioactivity is transferred from the ore towards the end products, which are in this case fertilizers (from 1980 till now).

2.2 The phosphate industry in Flanders

The five Flemish phosphate plants were visited and studied in detail. Figure 1 gives an overview of the quantities of ore that the phosphate industry in Flanders has processed between 1950 and 2006. The annual use of ore has been halved since the eighties down to 900 kton. This was due mainly to the closing of UCB in Ostend in 1987 and the moving of the basic phosphoric acid production facility of Prayon Rupel to Morocco in 1992 [5].

Figure 1: Yearly and cumulative use of phosphate ores in Flanders.



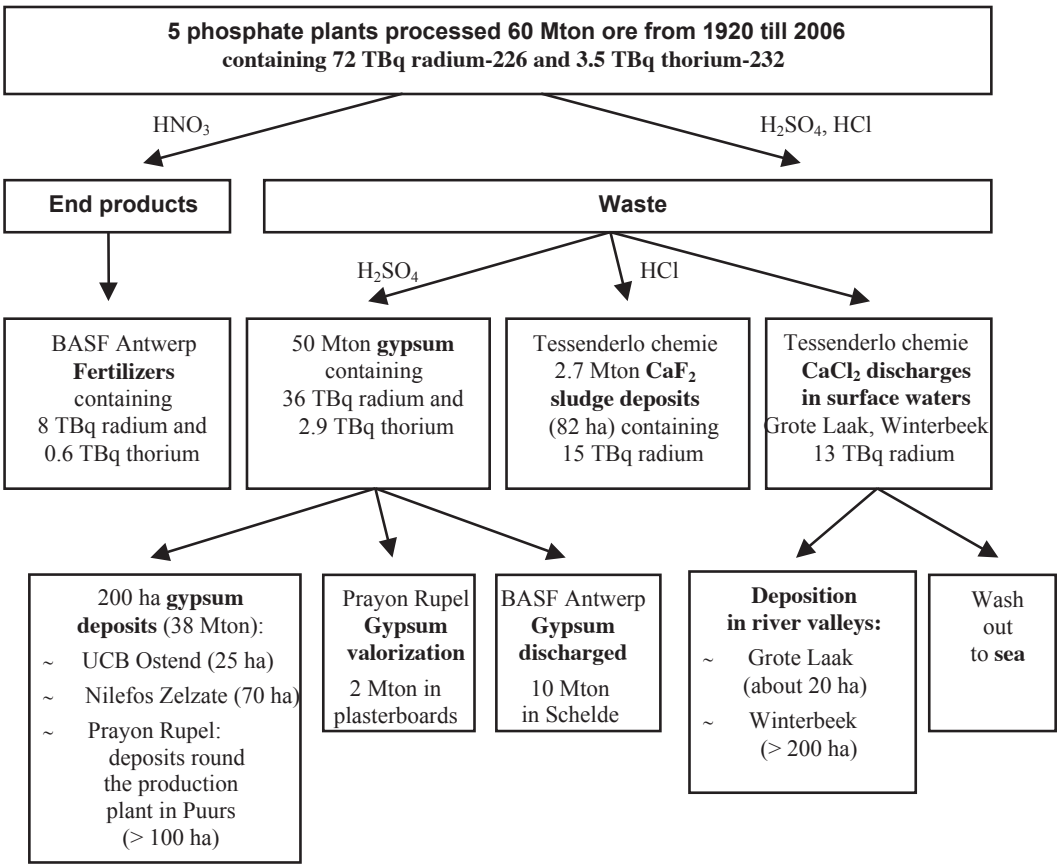
The five Flemish phosphate plants, from 1920 to 2006, handled 60 Mton of phosphate ore containing 72 TBq of uranium-238 (radium-226) and 3.5 TBq of thorium-232 in radioactive equilibrium with their decay products. In which by-products, residues or product streams this radioactivity turns up, is dependent on the processing method. The radioactive mass balance of the Flemish phosphate industry is given in figure 2. The total surface area of the phosphogypsum and calcium fluoride sludge deposits amounts to almost 300 ha. There is also environmental contamination in the valleys of the two small rivers receiving the waste waters of the hydrochloric production process: the Winterbeek (> 200 ha, banks and flooding zones) and the Grote Laak (20 ha, mainly banks).

2.3 The phosphate industry in the Walloon provinces

The data on the impact of the phosphate industry in the Walloon provinces in Belgium is less complete. Prayon Engis produced in 2004 0.8 Mton of phosphogypsum, valorizing about 70 % of the gypsum in building materials (plaster, cement), in fertilizers, and in other products such as paper. The remainder was stored on a local disposal site with a capacity of 9 Mton of which 3.75 Mton was used in the middle of 2002. Most of the current phosphate ores are of magmatic origin, mostly originating from Russia (Kola) with low specific radium-226 and thorium-232 concentrations.

Knauf Engis is the largest buyer of the phosphogypsum of Prayon Engis. In 2004 they valorized 0.4 Mton of phosphogypsum for the production of plaster. The activity concentration of the plaster was fairly low, about 30 Bq/kg for radium-226 and 50 Bq/kg for thorium-232 [2].

Figure 2: Overview of the impact of the phosphate industry in Flanders.



3. Other important NORM industries in Belgium

3.1 Iron and steel industry

The production of steel involves several stages clustered round a blast furnace whose purpose is to transform iron ore (on average 60 % Fe) into pig iron containing about 95 % Fe. During a visit at the blast furnace B of Mittal in Ougrée near Liège samples of products, by-products and waste materials were taken for analysis afterwards at SCK by high resolution gamma spectroscopy [1]. The activity concentrations of the natural decay series in the raw materials, iron ore and coal, are quite low, typically between 5 to 50 Bq/kg. During the iron and steel making process, selective concentration of specific radionuclides in by-products and waste materials takes place. The volatile lead-210 and polonium-210 are concentrated in the dust of the blast furnace. The dust is removed from the flue gas and recovered as sludge containing 25 to 60 kBq/kg of polonium-210. Most of the non-volatile radionuclides turn up in the blast furnace slag where activity concentrations for radium-226 of 160 to 165 Bq/kg were measured. 0.25 ton of slag is produced for each ton of pig iron. The totality of blast

furnace slag in the Belgian steel industry, about 2 Mton per year, is sold to the Belgian cement industry for the production of blast furnace cement.

3.2 Coal-fired power plants

The radiological impact of a coal-fired power plant, located in Langerlo in the north of Belgium, was evaluated [6]. The power station under investigation had two separate combustion units, producing 250 MW electrical power each. The finely pulverized coal fueling the power plant contains about 15 % of non-combustible material. This material turns up for more than 90 % in the flue gasses as fly ash, while the rest falls to the bottom of the combustion units as bottom ash. Electrostatic precipitators are in operation to remove the fly ash from the flue gasses. In 1999, flue gas purification systems for desulphurization and nitrification were installed, the so called DESOX and DENOX installations using limestone and NH_3 additives. Limestone ($CaCO_3$) binds to sulphur dioxide (SO_2) in the flue gases to form gypsum ($CaSO_4.2H_2O$), which is subsequently dehydrated and sold to the building industry for the production of plasterboards.

The radioactivity concentrations in the coal, fly ash, bottom ash and desulphurization gypsum were assessed. A summary of the gamma spectroscopy measurements is given in table 2. The natural radioactivity concentrates in the fly ash with a factor 7 to 9, and in the bottom ash with a factor 4 to 5, as could be expected, but due to the low radioactivity content of the utilized coal, this does not present considerable problems from a radiological protection point of view. The flue gas desulphurization gypsum contains hardly any natural radioactivity. The fly ash, the bottom ash and the gypsum are being used as raw materials in the building industry, so no waste problem exists. In today's practice, a maximum of 18 % (volume) of fly ash is added to cement. This leads to a 3 % (weight) fraction of fly ash in concrete, increasing the activity concentrations of the concrete by a few Bq/kg.

Table 2: Activity concentration ranges of the natural uranium and thorium decay series in coal and in by-products of a coal-fired power plant in Belgium.

	U-238 (Ra-226) Bq/kg	Th-232 Bq/kg
Coal	5 - 30	4 - 30
Fly ash	160 - 180	165 - 195
Bottom ash	90 - 100	85 - 100
Desulphurization gypsum	4 - 9	4 - 9

3.3 Non-ferro industry

The non-ferro industry is a widespread industry in Belgium with a large turn over of raw materials with normal concentrations of natural radioactivity. Exceptions are small amounts of the mineral cassiterite for the production of tin and coltan for the production of niobium and tantalum. The coltan mainly due to transit handling in the Antwerp harbor of the ores. The coltan slag on factory grounds from Sadaci near Ghent is dealt with in point 4 on the legacy from past NORM practices.

The non-ferro company Metallo-Chimique is located in Beerse in the north of Belgium. The company produces copper, lead and to a lesser degree tin, from various kinds of scrap, slag, crystal glass, tin and copper ashes. Sometimes, depending on the market supply, small amounts of raw materials, such as cassiterite (tin ore), are added. The production process is complicated with several meltings and reductions. There are no waste streams as all the by-products have a commercial value. The tin production in the period 1997 to 2001 was around 8000 ton per year, less than 5 % of the total output. Cassiterite generally shows high concentrations of the natural decay series. The ore is in Metallo-Chimique rarely if ever processed alone, but in combination with tin- or lead-containing minerals. As such, it forms only a small fraction of the total amount of raw materials. In the period 1997 to 2001 the yearly use of cassiterite was limited, varying between 147 and 623 ton. The cassiterite originated from

the area of the Great Lakes in Africa where it is extracted from river beds in a similar way as gold. The average activity concentrations of the cassiterite used by Metallo-Chimique were 16500 Bq/kg for the thorium and 1310 Bq/kg for the uranium decay series. The activity mass balance of the complicated production process was looked at by taking samples of the different input and output materials [1]. The results showed that most of the activity of the cassiterite ore turns up in the by products; the non-volatile radionuclides in the metamix slag and the volatile polonium-210 in the filter dust, both sold on the market. The pure metals contain very little radioactivity with the exception of some lead-210 in lead.

3.4 Zircon sand in lost wax casting

Zircon sand consists mainly of zirconium silicate ($ZrSiO_4$). It is used in Belgian workshops to make a refractory shell mold of a wax replica. Liquid metal is poured into the mold replacing the wax to produce a metal piece with the same dimensions of the wax model. After the metal is cooled, the shell is carefully broken away. The use of zircon for the first layer in a refractory mold produces a smooth surface on the metal.

The radiological impact of two companies using the lost wax production process was evaluated. The companies were visited and samples of the input and output materials were taken [1]. The activity concentration of the zircon sand used for the first layer of the molds was between 1500 to 3000 Bq/kg for the uranium series and between 200 to 300 Bq/kg for the thorium series. The bags of zircon sand were placed on pallets of 1740 kg. The dose rate in close contact with 4 of these pallets was 2 μSv/h. After casting the alloy, the shell is broken in a closed and well ventilated room without the presence of personnel in the room. Only a small fraction of the total amount of waste is zircon sand. The dilution factor was 9 in one of the companies and 35 to 50 in the other.

3.5 Extraction and purification of drinking water

As water is treated to remove impurities, radionuclides and in particular radium-226 present in the source water may concentrate in sediment or sludges. Most drinking water treatment sludges contain radium-226 levels comparable to typical concentrations in soils. However some water supply systems relying on groundwater sources may generate sludges with much higher radium-226 levels. Samples from a dozen randomly chosen drinking water wells in Belgium were analyzed [1]. Radium-226 concentrations up to a few kBq/kg (dry weight) were found in the sludge. The higher values were related to wells with a low sludge production of typically a few hundreds of cubic meter per year. The results indicate that this could be a frequent problem for groundwater sources. A survey over the entire country would give a clearer idea of the significance of this NORM issue in Belgium.

4. Legacy from past NORM practices

4.1 Former mining area of alum shale

Extraction of alum shale took place in the valley of the Meuse from the Middle Ages up to the second half of the nineteenth century. The mining area is extended and the sites are uncharted and hardly visible. A visit of two of these sites showed slightly enhanced dose rates up to 140 nSv/h. Four samples of the residues were taken presenting radium-226 concentrations between 115 to 145 Bq/kg [1].

4.2 Slag heaps from coal mining

Coal mining has been an important industry in Belgium from the eighteenth until the second half of the twentieth century. Impressive slag heaps still dominate the landscape in the former coal mining regions. Six waste coal piles in the Walloon provinces and two mining sites in Flanders were visited. Gamma dose rates were measured on site and samples were analyzed at SCK. The results were hardly enhanced compared to the natural radiation environment. The highest dose rate of 220 nSv/h was found in Heusden-Zolder, the last Belgian mine, which closed down in 1992 [1].

4.3 Coltan slag

Sadaci, a company located along the canal Ghent-Terneuzen, from 1960 to 1985 produced ferroniobium from columbite-tantalite ore (coltan). Coltan ore is generally rich in thorium and uranium. The radioactivity of the processed ore showed up in the slags with typical concentrations of 70 kBq/kg for thorium-232 and 5 kBq/kg for radium-226. The slags were used in the seventies for raising and leveling a factory ground of 4 to 5 ha. This ground is now partly covered with asphalt and partly fallow covered with grass. The slags were spread out and mixed with a large amount of materials with normal background. The dose rate in contact with the slag is 10 to 20 μSv/h, but because of the shielding by the surrounding material the dose rates measured 0.5 m above the surface were generally between 0.1 and 1 μSv/h [4].

4.4 Olen radium facility

The former radium facility at Sint-Jozef-Olen (1922-1969), located in the north of Belgium, was an economical success story. In a few decades, mainly before World War Two, Union Minière (now Umicore) produced about half of the total amount of radium in the world (4.5 kg). Radium was particularly used in medicine for radiotherapy and in the luminizing industry until cheaper and more efficient radionuclides became available. The decommissioning and dismantling of the industrial installations was finished in 1983 with the construction on factory grounds of a heavily engineered storage facility for the confinement and isolation of the dead stock and the radioactive waste.

Several areas in the vicinity of the radium facility were contaminated with radium. The major contaminated sites are shown in figure 3: the banks of a small river (Bankloop) receiving the liquid effluents, the former flooding zones (now an agricultural area) where the Bankloop flows into the Kleine Nete, a waste deposit of 9 ha with mixed radium and chemical waste (D1) at the surface and a few streets with contaminated material underneath (Kapellekensstraat and Grensstraat) [7].

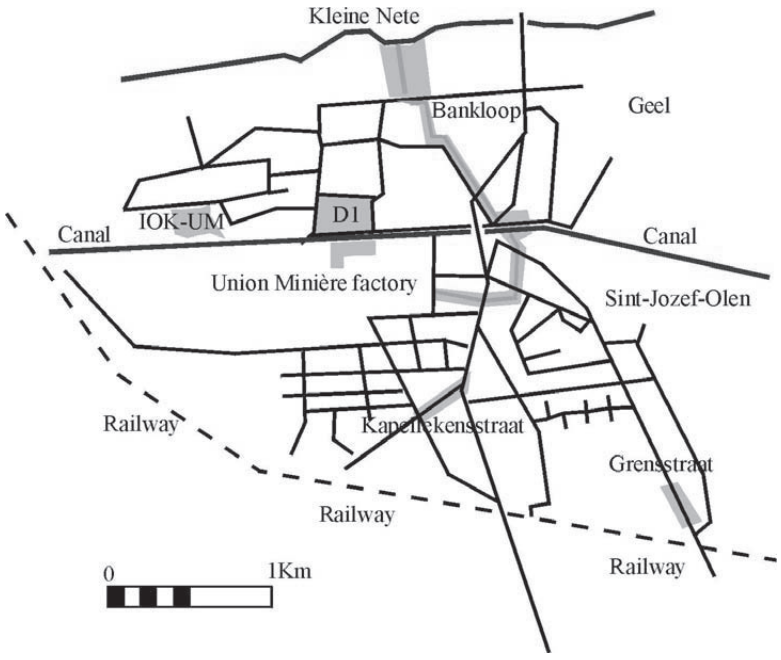


Figure 3: Presence of radium at Sint-Jozef-Olen. Areas with enhanced radium concentrations from past disposal activities or caused by liquid discharges into the Bankloop are indicated in grey.

Recurring media coverage since 1989 of some high contaminations in Sint-Jozef-Olen resulted in a detailed radiological characterization of the contaminated sites and an evaluation of their population impact. The population exposure from the contaminated river banks and streets is a few hundreds of μSv/year depending largely on the selected residence times and exposure levels. External exposure from the waste deposit (D1) is at the moment prevented by a fence. The internal contamination from local foodstuffs is limited to a few tens of μSv/year because there are at present no crops for direct human consumption on the contaminated farmland at the mouth of the Bankloop.

5. Conclusions

The EU Basic Safety Standards directive (BSS) of 1996 [3] deals with occupational exposure from natural radiation sources in a different way than ICRP 60 [8]. The EU BSS makes distinction between practices, which are functional applications of ionizing radiation, such as the use of radionuclides in view of their radioactive, fissile or fertile properties, and work activities where the unintentional presence of natural radioactivity lead to a significant increase in the exposure of workers or members of the public. The reason for the separate treatment of work activities in the EU BSS is the awareness that the strict regulation of artificial sources cannot be applied to the vast non-nuclear industry in the presence of a considerable and variable natural background.

The new ICRP recommendations, publication 103, are facing the same problem [9]. Unresolved in all of the draft documents, ICRP decided in March 2007 to consider exposure to NORM and exposure to radon always as an existing exposure situation. However, according their own definitions, exposure to NORM in a new installation and exposure to radon in a new dwelling or workplace, should fall into the category of planned exposure situations.

This “misclassification” as an existing exposure situation may be understandable in the case of indoor radon as the average radon exposure is already comparable to the dose limit for members of the public of 1 mSv/y. This “misclassification” is not so understandable in the case of exposure of workers to NORM in a newly built installation of the non-nuclear industry.

The EU BSS directive of 1996 sets up a stepwise system in which the Member States are required [3]:

- to make by means of surveys or by any other appropriate means a national inventory of NORM activities;
- to monitor exposures and to evaluate the related doses for each work activity identified;
- to implement, if necessary, corrective measures to reduce exposure;
- to apply, if necessary, all or part of the system of radiological protection for practices or interventions.

The mission of the Belgian agency for radioactive waste (ONDRAF/NIRAS) was extended in 1997 with the task of drawing up an inventory of all nuclear facilities and sites containing radioactive substances on Belgian territory [10]. Work activities, as defined by the EU BSS, were introduced in Belgian legislation in 2001 [11]. The sites of the non-nuclear industry on which natural radionuclides are found as a result of work activities are thus part of the scope of the inventory of nuclear liabilities. Since non-nuclear sites do not need nuclear licenses, their identification is a difficult task that ONDRAF/NIRAS entrusted to a task group consisting of SCK•CEN, Controlatom and the Dutch NRG. The results of this work program were presented in a report that gives an overview of the NORM industries in Belgium [1], on which this paper is largely based on.

The most relevant results are summarized in table 3 depending on the branch of industry. The table gives an overview of the measured range of activity concentrations and a rough estimate of the flow of materials in Belgium.

Table 3: Overview of the activity concentrations for the uranium series (uranium-238, radium-226, polonium-210, lead-210) and thorium-232 in de Belgian non-nuclear industry. Blanks indicate the absence of samples or measurements. The results are measured values and do not necessary represent the entire range. The production figures in the last column are only a rough estimate.

Industry	U-238 Bq/kg	Ra-226 Bq/kg	Po-210 or Pb-210 Bq/kg	Th-232 Bq/kg	Production or consumption kton/year
Phosphate industry					
Phosphate ore	55 - 1500	55 - 1500		20 - 800	1500
Phosphogypsum		50 - 1000		20 - 500	1500
CaF_2 sludge		2000-10000			50
Deposition in river valleys		- 10000			> 220 ha
Phosphoric acid	5 - 650				500
NPK fertilizer		- 150		- 20	2000
Iron and steel industry					
Blast furnace sludge		60 - 65	30 000 - 65 000	20 - 25	15
Blast furnace slag		160 - 165		35 - 40	2000
Coal-fired power plants					
Fly ash		160 - 180		165 - 195	500
Bottom ash		90 - 100		85 - 100	65
Non-ferro					
Cassiterite (tin ore)	1500 - 3000	1500 - 3000		8000-25000	0.5
Zircon sand	1500 - 3000	1500 - 3000		200 - 300	
Ground water collection sludge		5 - 1200		5 - 50	
Alum shale mining legacy		115 - 145		55 - 60	
Coal mining legacy					
Coal piles in the Walloon provinces	35 - 40	35 - 40		55 - 65	100 000 (tot.)
Mining sites in Flanders	55 - 100	55 - 100		65 - 200	
Coltan slag legacy		4600 - 5200		66 000 - 71 000	4 à 5 ha

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Distribution of doses resulting from cosmic rays exposure for Belgian airlines.

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Abstract. The Belgian Radiation Protection Act of 2001 requires air line companies registered in Belgium to evaluate the doses resulting from the exposure of their crew to cosmic radiation. If the annual dose of 1 mSv is exceeded, the crew must be informed about their individual doses and pregnant women have to be protected, among other measures. The Federal Agency for Nuclear Control (FANC, the competent Belgian radiation protection authority) has issued guidelines in order to help air line companies to fulfil their duties. Following the publication of these guidelines, all commercial Belgian air line companies have sent data on the exposure of their personnel. These data and, in particular, the distribution of the doses are presented. Except in the cases of small "air taxi" companies, which fly only on very short distances and low altitudes, a significant number of air crew members gets doses of more than 1 mSv/y. The maximum value amounts to ~ 4 mSv/y. The computer codes used by the companies in order to evaluate the individual doses are PCAIRE, CARI and IASON-FREE. The FANC imposed the concerned companies to reassess yearly the individual doses.

KEYWORDS: aircrew, cosmic radiation.

1. Introduction

The Directive 96/29/EURATOM, the European Basic Safety Standards, addresses the issue of the radiation protection of air crew against cosmic radiation[1] [1]. The Directive has been implemented in Belgium with the Royal Decree of July 20th, 2001 [2], setting forth the general regulation for the protection of the population, the workers and the environment against the danger of ionizing radiation. In 2007, the Federal Agency for Nuclear Control (FANC) - the competent Belgian radiation protection authority - has campaigned among Belgian commercial air line companies to make them aware of their legal obligations with respect to the radiation protection of air crew. As a result of this campaign, all Belgian air line companies have complied with their obligations and sent data about the doses of their personnel to the FANC. This paper gives an overview of the Belgian regulatory framework for radiation protection of air crew and presents a synthesis of the data received from Belgian air line companies.

2. Belgian regulations

2.1 Royal Decree of July 20, 2001

In the Royal Decree of July 20th, 2001 companies operating aircrafts are defined as "work activities involving enhanced exposure to natural sources" that have to submit to the FANC a notification, which must contain:

- the administrative data of the company;
- a description of the methods for measuring or evaluating the exposure of the personnel to cosmic radiation;
- the results of these measurements or evaluation.

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[1] In addition, Joint Aviation Authorities have implemented similar requirements into the rule JAR-OPS 1.

If the dose level of 1 mSv/y is exceeded or likely to be exceeded, the companies must, in addition:

- assess the individual doses of the personnel resulting from exposure to cosmic radiation;
- take into account these dose assessments in the organisation of the working schedules with the aim to reduce the doses of highly exposed air crew members;
- inform the concerned workers of the health risks from their work;
- limit the doses during pregnancy.

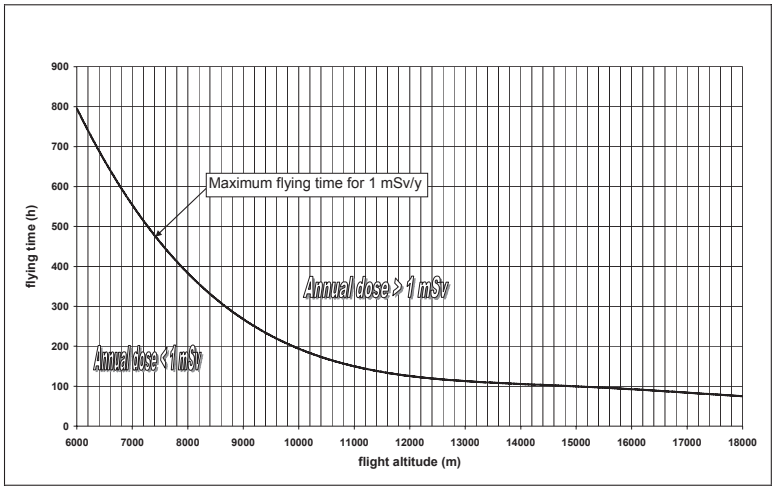
It is also stated that, from the moment of the declaration of pregnancy, the conditions for the pregnant woman in the context of her employment shall be such that the dose to the unborn child will be as low as reasonably achievable and that the dose may not exceed 1 mSv **for all the duration of the pregnancy**. If this dose is already exceeded at the moment of the declaration of the pregnancy, the pregnant woman will be excluded from any work with a risk of exposure to ionising radiation.

2.2 Technical guide about the exposure of aircrew to cosmic radiation

To help operators of air lines to fulfil their obligations and to better specify the content of their notification file to the FANC, a technical guide has been published, which describes in more detail the procedures of the dose assessment [3]. The guide contains a few straightforward criteria to readily assess whether air crew members are unlikely to receive an annual dose higher than 1 mSv. These criteria are the following:

- criteria 1: the company operates air planes with a maximum flight altitude of 6000 m and the flying time does not exceed 770 hours;
- criteria 2: the company operates air planes with a maximum flight altitude of 14,000 m and the flying time does not exceed 100 hours;
- criteria 3: based on the graph in Figure 1, it is possible to conclude that no air crew member gets an annual dose higher than 1 mSv. This graph comes from the regulations developed by the German civil aviation authorities (Luftfahrt Bundesamt) [4].

Figure 1: Delimitation of the zone where the annual dose may be higher than 1 mSv as a function of flying time and flight altitude



If none of these criteria applies, the company must evaluate the dose using a computer code, such as CARI, EPCARD, etc. Note that there is no system of accreditation in Belgium for this type of software.

If the annual dose is higher than 1 mSv, the annual individual dose of each concerned air crew member must be communicated. If the dose is higher than 6 mSv/y, the **monthly** individual dose must be communicated.

3. Results from the notification of air line companies in Belgium

3.1 Short overview of Belgian commercial air line companies

Following the publication of the guidelines mentioned in section 2.2, the FANC, in collaboration with the Belgian aviation authorities, contacted all Belgian commercial aircraft operators and organised an information session.

10 Belgian commercial air line companies submitted a notification to the FANC:

- 5 are mainly operating business flights inside Europe;
- 2 are freight carriers;
- 2 are mainly operating charter flights for holiday tours, to North Africa and to the Caribbean;
- 1 is a "regular" air line company, flying mainly to European destinations but also long haul destinations, essentially in Africa and North America.

3.2 Methods of evaluation of the doses

Among the 10 companies, 3 used one of the three straightforward criteria described in section 2.2 to claim that their personnel was unlikely to receive doses of more than 1 mSv/y. Two of these "exempted" companies are "air taxi" companies; they use carriers like Fokker 50 or Embraer 121, the altitude of which is limited at 6000 m. The third company is a freight company doing mainly intra-European flights.

The other companies used a computer code to assess the doses of their personnel: two companies used IASON FREE, one used CARI, one PCAIRE and the last one did not specify the software used. Note that all these three software packages are referred to in the European Commission Report "Radiation Protection 140" [5].

3.3 Results of dose distribution

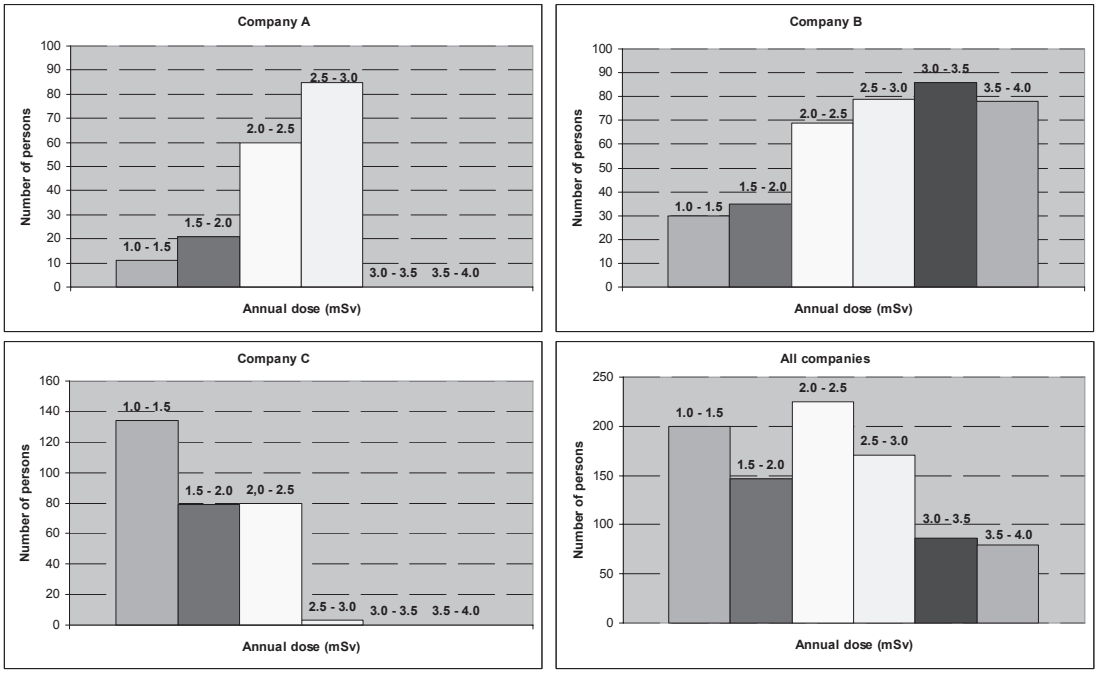
According to the dose assessment, a significant number of air crew members gets a dose higher than 1 mSv/y, although nobody gets a dose above 6 mSv/y. For 907 air crew members, the dose is higher than 1 mSv/y and for 522 less than 1 mSv/y. Table 1 gives an overview of the mean and maximal dose for the five most significant companies, along with the total number of air crew members. Note that the mean dose has been calculated on air crew members with a dose higher than 1 mSv/y, as the individual dose must only be registered in that case.

Table 1: Number of air crew members, maximal and average dose.

	Number of air crew members with a dose ≤ 1 mSv/y	**Number of air crew members with a dose > 1 mSv/y**	**Maximal dose (mSv/y)**	**Average dose (mSv/y)**
Company A	26	178	2.9	2.4
Company B	25	377	4.0	2.8
Company C	245	297	2.7	1.6
Company D	28	33	3.7	2.0
Company E	198	22	1.6	1.3

Fig. 2 gives the dose distribution for companies A, B and C for the category > 1 mSv/y. As the two other companies only have a limited number of personnel in this category, their dose distribution is not as representative. The global dose distribution for all companies is also given.

Figure 2: Dose distribution for companies A, B, C and global distribution for all companies (for the category > 1 mSv/y)



The distributions of doses of the different companies display various patterns. For company C, most of the personnel get an annual dose in the range 1 – 1.5 mSv. For companies A and B (two charter companies), most of the personnel stands in the upper range of the distribution. It should also be noted that about half of the personnel is female.

Table 2 gives an overview of some of the routes which give the highest dose, along with the software used to evaluate that dose.

Table 2: Dose as a function of route

Route	**Dose (μSv)**	**Software**
Brussels – Montego Bay (Jamaica)	52	PCAIRE
Brussels – Varadero (Cuba)	48	PCAIRE
Cancún (Mexico) - Brussels	48	PCAIRE
Hurghada (Egypt) - Brussels	25	PCAIRE
Hurghada (Egypt) - Brussels	16	CARI

Note the difference between the result given by PCAIRE and CARI for the route Hurghada – Brussels. However, it is not clear whether this discrepancy is related to the software or to a difference in the flight profiles (altitude, for example).

3.4 Response to the companies

After receiving the data from the companies, the FANC replies to each of them and restates the obligations mentioned in Section 2.1. Emphasis is made on the necessity to inform the personnel about their dose, and to communicate the results of the individual dose assessment to the company's medical officer. Special attention is drawn to pregnant women. In most cases, however, pregnant aircrew members are anyway removed from flying due to reasons independent from radiation protection: depressurisation, jet lag, etc. Finally, the companies are requested to reassess the doses yearly and communicate the results to the FANC.

4. Conclusions

A large majority of air crew members receives an annual dose of more than 1 mSv. The dose distribution pattern differs according to the specific working conditions of the air lines.

Doses are only registered since 2007, but the evolution of the dose distribution will be followed in the future, in order to answer some pertinent questions like e.g. Are the air line companies able to take into account the reduction of dose in the organisation of the flying schedule? What are the parameters affecting the distribution?
Moreover, the regulatory framework has to be defined more precisely: Should air crew members be considered as professionally exposed workers or not? If yes, which kind of medical follow-up will be the most adapted to the specific characteristics of their exposure?

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The Belgian regulatory framework for NORM industries: test-case of a phosphate production plant.

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Abstract. According to the Belgian radiation protection regulatory framework, some categories of NORM industries must register to the competent Belgian radiation protection authority (FANC, Federal Agency for Nuclear Control). The facilities must provide a set of information which allows the authority to assess the radiological impact of the industrial activity on the workers, the population and the environment. If the dose exceeds or is likely to exceed 1 mSv/y, corrective measures have to be implemented. FANC has issued a methodology in order to define more precisely the data needed to evaluate the radiological impact. The methodology lists also the exposure pathways which have to be taken into account and the relevant parameters for the evaluation of the doses. The case of a phosphate production plant is discussed in more details: although the exposure of the workers in the production process as such is rather limited, the specific activity of some residues (calcium fluoride sludge) reaches around 10 kBq/kg of Ra-226. This sludge is disposed off in a specific landfill for which a program of radiological monitoring has been implemented. It includes periodic measurements of dose rate and radon concentration on the landfill.

KEYWORDS: NORM, natural sources, phosphate

1. Introduction

Title VII of the European Basic Safety Standards [1] addresses the issue of *significant increase in exposure due to natural radiation sources*. It recommends the Member states of the EU to identify the work activities which are of concern and to request the *setting up of appropriate means for monitoring exposure*. Title VII has been implemented into Belgian regulation with the Royal Decree of July 20, 2001 setting forth the general regulation for the protection of the population, the workers and the environment against the danger of ionizing radiation. The Belgian regulation sets up a positive list of work activities involving natural radiation sources and requires the concerned facilities to submit a notification to the Federal Agency for Nuclear Control (FANC) - the competent Belgian radiation protection authority. One of the difficulties in the assessment of the potential risk of radiation exposure in these facilities is to identify the correct parameters: NORM industries cover a large range of production processes and the concentration of natural radionuclides may be very dependent on the details of the production process. The FANC developed a methodology to help the operators of NORM facilities to identify the relevant parameters for the radiological impact assessment.

2. Belgian regulations with respect to NORM industries

2.1 The Royal Decree of July 20, 2001

The EURATOM Directive has been implemented in Belgium with the Royal Decree of July 20, 2001 [2], setting forth the general regulation for the protection of the population, the workers and the environment against the danger of ionizing radiation. Articles 4 and 9 of this Royal Decree address specifically the issue of NORM industries. Article 4 lists the work activities which require regulatory consideration. In addition to workplaces involving a risk of exposure to radon and to airlines companies, its lists the following NORM industrial sectors:

- phosphate production;
- zirconium industry;
- tin foundries;
- rare earths extraction;
- manufacture of thoriated welding electrodes.

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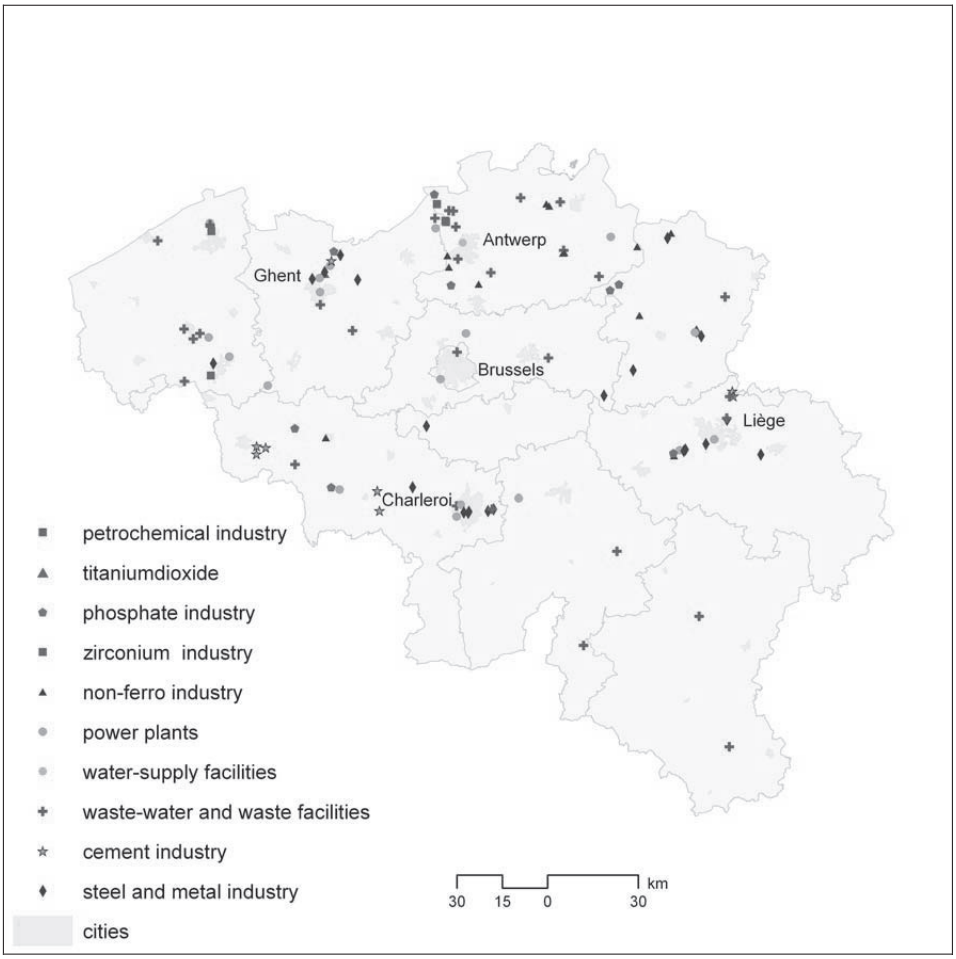
The FANC has the possibility to amend this list. An overview of the locations of known NORM industries in Belgium is given in Fig. 1. Note that this map includes also categories of NORM industries that are not yet submitted to regulatory consideration.

Figure 1: Locations of NORM industries in Belgium



Article 9 defines the legal obligations of these industries. They must submit to the FANC a notification with the following elements:

- the administrative data of the facility;
- the type of facility;
- the type and the characteristics of the natural sources of radiation which are present or processed in the facility;
- the description of the processes which may lead to an enrichment of the radionuclides;
- the number of concerned workers in the facility;
- the protection measures which are already installed or foreseen, and, if applicable, the physical state of these natural sources, their quantities, their level of radioactivity, their destination & the places where they are stored or processed;
- a description of the measures concerning the characterisation, the treatment, the storage and elimination of the produced residues.

Based on the elements of the notification, a rough dose assessment is performed by the FANC. The reference dose level is the dose limit for public - 1 mSv/y. If this dose level is exceeded or likely to be exceeded, the FANC may impose to the facility some corrective measures. If, in spite of these corrective measures, the dose level of 1 mSv/y is still exceeded, the NORM facility may become a licensed facility.

2.2 Methodology

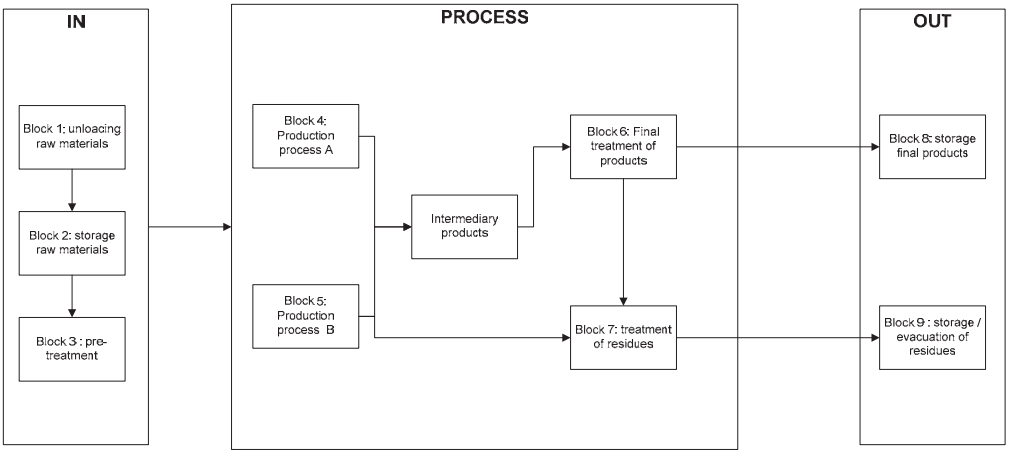
Many operators of NORM facilities are not familiar with radiation protection issues. Hence, it is not always easy for the operators to apprehend correctly the legislation. Moreover, the production processes in NORM industries may be very complex, making identification of the critical points with respect to radiation exposure in the processes a challenging task. In order to help the operators in filling their notification, the FANC developed a technical guide [3] giving more details about the content of the notification and the relevant parameters for radiological impact assessment and providing a standardized format for these notifications. The standardization of the format allows a swifter identification of the critical points of exposure. This guide can be downloaded from the website of the FANC along with a fact-sheet about NORM[1].

The notification is based on two main elements: a **flowchart** of the production process and a **table** summarizing all the relevant parameters for the impact assessment.

Fig. 2 gives a generic example of a flowchart; the process is divided into blocks and a clear distinction is being made between the input, the output and the production operations as such.

The operator must briefly describe each of the blocks including all maintenance operations.

Figure 2: Generic example of a production flowchart



For each of the blocks, the operator must fill in a table with a set of data: the table lists the different work premises and the name of the products, the physical data about the products (physical state, quantities, granulometry, dust concentration in the premises), radiological data (specific activity of the radionuclides, exposure time, number of exposed persons, dose rate and radon concentration), protection and surveillance measures (collective and individual protection measures, impact outside the site, surveillance measures, accessibility of the premises).

[1] http://www.fanc.fgov.be/fr/page/problematique-«-norm-»-dossier-d-information/363.aspx

Based on these parameters, a rough estimation of the dose to the workers may be calculated. This estimation takes into account all relevant exposure pathways: external irradiation, inhalation of dust and – if relevant – of radon gas and, to a lesser extent, ingestion of dust.

2.3 Response from the facilities

Following the development of the methodology in 2007, the FANC has treated seven notifications from NORM facilities: three from the phosphate production sector, three from the zirconium industry and one tin foundry. Of course, this represents only a tiny amount of the total number of NORM facilities in Belgium (see Fig. 1). This shows the necessity for better informing and sensibilising the NORM industries about radioprotection issues and to overcome the reluctance of some operators to face their legal obligations.

None of the seven facilities which have been assessed needed to be licensed. In many cases, it was highly unlikely that the dose level of 1 mSv/y was exceeded. Maintenance operations are generally the most critical. However, the protection measures against non radioactive hazards (ventilation, respiratory protective equipment …) are generally sufficient to efficiently protect against significant exposures.

In the next section, we will focus on a phosphate industry where more detailed monitoring measures were imposed.

3. Test-case of a phosphate production plant

3.1 Short description of the production process

The facility processes sedimentary phosphate ores into dicalciumphosphate, which is used for cattle food. The phosphate ores arrive by boat and are stored into a vast hall. The ores are grinded and dissolved with hydrochloric acid in dissolution tanks. The washing of the solution gives rise to vast amounts of calcium fluoride sludges, which are pomped and then treated as waste and disposed on a landfill located on the site of the facility (see section 3.3).

After washing, the solution goes to a process of decantation and filtration to result into dicalciumphosphate.

3.2 Radiological data in production and maintenance operations.

The specific activity of uranium in the phosphate ores amounts to ~ 1.5 kBq/kg. Uranium is in secular equilibrium in the ores, but the equilibrium will be broken as a result of the production process, with uranium going into the final products and radium into the residues.

In the hall where the ores are stored, radon concentration levels up to 250 Bq/m^3 have been measured (the radon background level in the area is around 10 Bq/m^3 in open air). Almost all the operations of the daily production process occur in closed phase, so that exposure of workers in routine production process is almost negligible.

In maintenance, the most critical operation is the cleaning of the dissolution tanks. Due to an important scaling of radium on the walls of the dissolution tanks, the dose rate in contact with these walls reaches ~ 10 µSv/h. Maintenance workers have to wear individual protection equipments (respiratory protective equipement, safety gloves and overall) during this operation.

3.3 Treatment of residues

The calcium fluoride sludges are pomped into the so-called *filter-press building* where mechanical dewatering occurs by action of the filter-press. This results into dried filter-cakes which are disposed off on the landfill. These filter-cakes contain almost all the radium of the process. The specific activity of radium-226 in the filter-cakes amounts ~ 10 kBq/kg.

Note that before the 1990's a large amount of CaF_2 stayed in suspension in the waste-water, which led to a significant radium concentration in the discharged water, 20 – 25 Bq/l. The waste water is discharged into two small rivers and the relatively high radium concentration of the past led to a contamination of the river bed and banks (where radium concentrations up to ~ 8 kBq/kg have been measured). Since the 1990's, an appropriate treatment of waste-water allowed the precipitation of most of the radium, so that the radium concentration in the discharged water decreased to ~ 2 Bq/l. But the result obviously was an increase of radium concentration in solid waste, which led to the above mentioned activity.

Around 100,000 tons of CaF_2 are produced yearly: several landfills have already been filled up. On the active landfill, a few workers are occupied full-time. The dose rate measured at the surface of the landfill is significant: up to 2.6 µSv/h (the background level in the area is around 0.1 µSv/h). Inside the cabin of the bulldozer used by the workers, a dose rate of 0.7 µSv/h has been measured. Consequently the yearly exposure due to external radiation for a worker who is full-time[2] occupied in the bulldozer on the landfill should amount to ~ 1 mSv/y - just around the dose limit for the public. In order to check that number, these workers have been requested to wear dosimeters. Surprisingly, the dose measured by the dosimeters doesn't seem to be significant. However, it has yet to be investigated if this low value of the dose is due to an improper use of the dosimeters or to the fact that the effective time of presence of the workers on the landfill is much lower than 1600 hours.

In addition to the external dose rate, significant radon concentrations have been measured in open air at the surface of the landfill. A network of a dozen of measurement points has been established; some of the measurement points are situated on the active part of the landfill, some on the inactive part (part already filled up) and some in the direct environment. Table 1 gives the average value of radon concentration on the active and inactive part of the landfill for the years 2005 and 2006. As already mentioned, the radon background level in open air in the area is around 10 Bq/m^3.

Table 1: radon concentration measurements (Bq/m^3) on the active and inactive part of the landfill

Year	Active part of landfill	Inactive part of landfill
2005	69	255
2006	70	265

The filter-press building, where the mechanical dewatering of the waste occurs, is located just next to the landfill. Significant radon concentrations are measured inside the building. As a few workers work full-time in this building, the radon concentration needs to be verified systematically. The table below gives the figures of radon concentrations at several measurement points inside the building.

The measurement points 5 and 6, where the highest concentrations have been measured, are located on the ground floor of the building (room with the pumps). Several measures to improve the efficiency of the ventilation of the building have been taken in the last few years, which led to a decrease of the radon concentration to the current level.

[2] Around 1600 hours of occupancy.

Table 2: Radon concentration measurements (Bq/m^3) in the filter-press building at six measurement points

Year	1	2	3	4	5	6
2000	338	203	319	215	829	1074
2001	336	248	233	209	350	462
2002	241	151	186	135	239	346
2003	208	156	164	154	200	263
2004	244	155	134	121	220	298
2005	135	111	144	68	180	242
2006	126	81	180	78	188	218

3.4 Evaluation by the FANC

Workers employed in routine production operations are not at risk of significant exposure. For maintenance operations, some precaution measures have to be taken to keep the dose as low as reasonably possible. Workers involved in the treatment of the residues may be exposed to a dose which is slightly higher than 1 mSv/y due to external radiation; moreover, they are also exposed to an increased radon concentration. As part of the graded approach to regulation commonly applied for NORM facilities, the FANC decided not to impose a system of licensing to this facility; consequently, the workers are not considered as professionally exposed. But, in order to be able to follow-up the radiological impact of the activities of the facility, a program of measurements has been enforced which includes:

- periodic measurements of dose rate at the surface of the landfill;
- monitoring of the dose received by the workers employed on the landfill;
- periodic measurements of radon concentration on and around the landfill and inside the filter-press building.

4. Conclusion

The regulatory approach for NORM industries in Belgium is based on a positive list of industrial sectors and on a graded approach to regulation. NORM industries have to submit a notification to the FANC and the latter decides case-by-case on the appropriate response based on a radiological impact evaluation. The regulatory response may range from doing nothing to licensing or to the enforcement of a radiological monitoring program. FANC developed a methodology to quickly identify the critical points for radiation exposure.

In the example from the phosphate industry, which has been presented in section 3, the critical points were some maintenance operations and the treatment of the residues, which seems to be a generic characteristic of NORM industries. Although the dose in this particular case could be higher than 1 mSv/y, no licensing was imposed but a program of follow-up of dose rate and radon concentration was enforced.

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Intercomparison of Extremity Dosimeters in Beta, Photon and Medical Realistic Fields

Performance of ring dosimeters in typical medical fields

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Abstract. The EURADOS Working Group 9 is presently coordinating research activities on the assessment of occupational exposures at workplaces in therapeutic and diagnostic radiology as well as in nuclear medicine. A recent literature review showed that extremity doses, especially in nuclear medicine and interventional radiology, can be quite high. However, the use of extremity dosimeters in hospitals is still not very common. Furthermore, there is very little information on the performance of these dosimeters in typical medical fields. Within this framework, EURADOS organized an intercomparison of ring dosimeters aimed at assessing the technical capabilities of available extremity dosimeters and focusing on their performance at workplaces with potentially high extremity doses. 24 services from 16 European countries participated in the intercomparison. The dosimeters represented in this study are used to monitor over 30,000 workers. The dosimeters were exposed to reference photon (^{137}Cs) and beta (^{147}Pm, ^{85}Kr and ^{90}Sr/^{90}Y) fields as well as to realistic interventional radiology (direct and scattered radiation) and nuclear medicine fields (^{99m}Tc and ^{18}F). This report presents the main results of the intercomparison. It is shown that most dosimeters provided satisfactory measurements of $H_p(0.07)$ for photon radiation, both in reference and realistic fields. However, only four dosimeters fulfilled the requirements given by the trumpet curves for all tested radiation qualities. The main difficulties were found for the measurement of low energy beta radiation. A clear correlation between filter and detector thickness and response to beta particles was found, thus highlighting the need for appropriate dosimeter design for these fields. Finally, the results also showed a general under-response of detectors to ^{18}F, which was attributed to the difficulties of the dosimetric systems to measure the positron contribution to the dose.

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KEYWORDS: intercomparison, extremity dosimetry; nuclear medicine; interventional radiology; brachytherapy; TLD

1. Introduction

The European Radiation Dosimetry Group, EURADOS (www.eurados.org), is a scientific network of European laboratories involved in research in radiation dosimetry. The objective is to advance the scientific understanding and the technical development of the dosimetry of ionising radiation by stimulating collaboration between European facilities. In 2005, a new working group, (working group 9, WG 9) was created to coordinate research activities on the assessment of occupational exposures at workplaces in therapeutic and diagnostic radiology as well as in nuclear medicine. The group was funded through the CONRAD Project, within the 6th EU framework programme. The rapidly evolving medical practices and the introduction of new techniques require the implementation of special monitoring programmes. For some of these applications the skin of the fingers is the limiting organ for the individual monitoring of external radiation [1].

WG9 investigations also highlighted that there was very few available information about official extremity dose records [2] and that the registered doses were much lower than the estimations of annual extremity doses published in dedicated studies. These discrepancies were assumed to be due to the fact that (i) the dosimeters may not be systematically worn (ii) the most exposed workers may not be monitored and/or (iii) the dosimeters may be worn at not adapted positions or may not be suitable for the radiation field of interest, thus leading to significant underestimations of the doses.

Only few extremity dosimeter intercomparisons have been reported. In 2000 EURADOS organised an intercomparison as part of a performance test of services for dose assessment [3], which included some tests for extremity dosimeters. The results of the extremity dosimeters showed that, in general there were difficulties to obtain suitable results for low beta measurements. Seven years ago, another intercomparison was organized by the PTB (Germany) for extremity dosimeters in beta and/or photon radiation fields [4]. The study was more oriented towards the testing of the extremity dosimeters for the German requirements.

Based on the above mentioned observations, the organization of a European intercomparison, which would address ring dosimeter performance in reference and realistic fields, was considered of great value to the dosimetric community. EURADOS WG 9, in cooperation with several calibration laboratories and a hospital, organized such an exercise in 2007. The intercomparison is, to the best of our knowledge, the first organized on international basis that analysed the response of extremity dosimeters to typical medical fields. This paper describes the intercomparison set up and its main results.

2. Materials and Methods

2.1 Organization of the intercomparison exercise

In most situations where the extremities are irradiated, the skin is the part of the extremity receiving the highest dose and as the dose limits for skin and for the extremities are the same, the skin of the extremities is, generally, the limiting organ. The corresponding operational quantity is the personal dose equivalent, $H_p(0.07)$. The scope of the intercomparison was aimed at testing the capacity of ring dosimeters to measure the quantity $H_p(0.07)$. The irradiation programme included photon and beta fields in both reference and realistic conditions.

The following irradiation conditions were selected:

Reference fields :

- Photon: ^{137}Cs sources at 0°, 60° and 180°.
- Beta: ^{90}Sr/^{90}Y, ^{85}Kr and ^{147}Pm sources at 0° and 60°.

Realistic medical fields:

- Interventional radiology (IR): 70 kVp, with a filtration of 4.5 mm Al and 0.2 mm Cu, produced by a medical X-ray generator MPH65 (GEMS) (in two positions, within the geometrical limits of the primary radiation beam - direct radiation - and in the penumbra in the scattered field at the edge of the patient phantom - scattered radiation).
- Nuclear medicine: A 3 ml polyethylene unshielded syringe with ^{99m}Tc (gamma emitter) and ^{18}F (positron emitter).

The delivered doses varied from 1 mSv to about 11 mSv. The relevant ISO standards were used for the reference irradiations, ISO 4037 and 6980 series [5,6]. The irradiations were performed using the ISO rod phantom, which is a PMMA cylinder of 19 mm diameter and 300 mm length [7,8].

Irradiations were performed in four laboratories: Institut de Radioprotection et de Sûreté Nucléaire (IRSN), Commissariat à l'énergie atomique, LIST, Laboratoire National Henri Becquerel (CEA-LIST-LNHB), (France); Bundesamt für Strahlenschutz (BfS) (Germany); and the University of Brussels and Academic Hospital (AZ-VUB) (Belgium) in collaboration with the Belgian Nuclear Research Centre (SCK-CEN), (Belgium).

The ^{137}Cs source of IRSN (France) was used in the horizontal beam configuration as part of the photon irradiation programme. The second part of the photon irradiation programme was performed at CEA-LIST-LNHB (France) using a diagnostic X-ray facility in order to simulate irradiation at interventional radiology fields. The beta irradiations were performed at the BfS (Germany). Finally, the realistic nuclear medicine irradiation set-up was performed at AZ-VUB (Belgium). A syringe filled with the selected radiopharmaceutical was placed vertically, encircled by 22 rod phantoms equidistant to the syringe and located at 14.05 cm distance from the dosimeters. The extremity dosimeters were placed on the surface of each phantom, centred on it and facing the syringe [9]. The tests were designed to reproduce fields of interest in medical applications and to verify the ability of the participating dosimeters to determine $H_p(0.07)$.

Twenty four services from sixteen countries participated in the intercomparison. Most of the dosimeters (21/24) used LiF phosphors as detectors with different types of dopants, isotopic concentration of Li and thicknesses. Fifteen services used as sensible material LiF:Mg,Ti of standard thickness 0.9 mm (commercial name: TLD-100, MTS-N, DTG4). Nine services used the more sensitive material, LiF:Mg,Cu,P, four of them of standard thickness, 0.9-0.4 mm, (TLD-100H, TLD-700H), the other five with a thin sensitive layer of approximately 8 mg/cm^2 (MCP-Ns). Two services used $Li_2B_4O_7$ detectors and one service CaF_2:Mn. The filter material was, in most of the cases (18/24), plastic of thickness 3-30 mg/cm^2. The overall thickness of the detectors and filters ranged between 12 and 300 mg/cm^2. More information about the type of detector and filter used by each service can be found in Carinou et al. [10]. Most of the dosimeters were calibrated to Cs^{137} sources, while five services also used X-rays from the ISO 4037 series [5] to calibrate their dosimeters.
Each participating service was asked to prepare two dosimeters per irradiation field, 26 dosimeters for the irradiations and 8 detectors for background correction. Four of the services participated only in the photon fields: ^{137}Cs sources and interventional radiology fields.

2.2 Determination of reference $H_p(0.07)$ values

For ***^{137}Cs irradiation fields***, $H_p(0.07)$ was determined according to equation (1):

$$H_p(0.07) = h_p(0.07, a) \cdot K_{air}, \qquad (1)$$

where: $h_p(0.07, a)$ is the conversion coefficient from air kerma free in air to $H_p(0.07)$ for an irradiation angle a, provided by Grosswendt [11]. K_{air} is the reference air kerma free in air.

K_{air} is measured at IRSN using a secondary standard ionization chamber traceable to the primary laboratory at the CEA-LIST-LNHB. The overall uncertainty for $H_p(0.07)$, for ^{137}Cs irradiation, is equal to 4.8% (k=2). The main contribution of the uncertainty budget being due to the uncertainty on the air

kerma free-in-air to $H_p(0.07)$ conversion coefficients, taken as 4% (k=2), following ISO 4037-3 recommendations [7].

For ***interventional radiology fields***, $H_p(0.07)$ was determined using equation (1). K_{air} value was measured at CEA using an ionization chamber traceable to its French primary standards. The photon spectra in terms of fluence were calculated with the MCNPX Monte Carlo Code [12] at the two points of tests [13]. The average conversion coefficients from air kerma free in air to personal dose equivalent, $h_{p,K}(0.07, a)$, for the IR beams, were then derived from the calculated spectra (taking both angle and energy into account) folded with the individual conversion coefficients taken from ICRU 57 [14]. The total uncertainty on the reference value is 6.5% (k=2).The uncertainty budget includes the uncertainty on the air kerma measurement (5%, k=2), the statistical uncertainties on the calculated spectra (0.1%, k=2) and the uncertainty on the calculation of the conversion factors $h_p(0.07, a)$ (4%, k=2). Extra calculations have been done to evaluate the influence of multiple scattering between patient and worker phantom, but the influence of this was smaller than 0.1%.

For ***beta fields***, reference values of $H_p(0.07)$ were provided directly by a BSS-2 secondary standard traceable to the primary laboratory at the PTB. The reference value is calculated according to equation (2):

$$H_p(0.07) = h_{p,D}(0.07, a) \cdot D_t(0.07), \qquad (2)$$

where $h_{p,D}(0.07, a)$ is the conversion coefficient from absorbed dose in 0.07 mm of ICRU tissue, $D_t(0.07)$, to personal dose equivalent for an irradiation angle a.

It was assumed that the conversion coefficient $h_{p,D}(0.07, 0^o)$ is equal to 1 Sv/Gy. For the irradiation at 60º, $h_{p,D}(0.07, 60^o)$, the ISO 6980-3 value was used [8].

The total uncertainty in the reference values was equal to 2.3% for $^{90}Sr/^{90}Y$ and ^{85}Kr, and 3% - 3.7% for ^{147}Pm (k=2). It includes uncertainties of the source activity and its decay, those for the correction factors for the air density and attenuation (temperature, humidity and pressure), the irradiation time span and the uncertainty due to the geometry of the set-up because several detectors were irradiated on the rod phantom simultaneously. By convention, no uncertainty was assigned to the conversion coefficient in this case.

For ***nuclear medicine fields***, the reference values of $H_p(0.07)$ were calculated using the MCNPX [12] and the PENELOPE [15] Monte Carlo codes, normalized by the measured activity of the radioactive solution. A simplified set-up was defined in the simulation model compared to the experimental geometry. The radiopharmaceutical was simulated as a cylindrical water source limited by a 0.75 mm thick, 0.93 g cm^{-3} polyethylene syringe wall. The whole geometry was surrounded by dry air of 1.205 g cm^{-3}. For each solution (^{99m}Tc and ^{18}F), decay data were taken from Brown and Firestone [16] and Stabin and da Luz [17]. For the ^{18}F problem, 511 keV annihilation gamma-rays were taken into account as created where each positron (beta-ray) came to rest. The dose equivalent $H_p(0.07)$ was estimated as the dose deposited in a 0.5 cm height water cylindrical cell at 7±1 mg cm^{-2} depth within the phantom (2 mg cm^{-2} thick). The rod phantom was simulated as a 10 cm high, 1.9 cm thick water cylinder, with the front wall located at 14.05 cm from the centre of the source cell. Photons and electrons were transported in the MCNPX calculations, following the method recommended by Schaart et al. [18]. For ^{18}F it was observed that 57% of the total $H_p(0.07)$ value is due to direct exposure to positrons and 43% due to annihilation gamma-rays. Calculated deposited doses were expressed in terms of Sv per ^{99m}Tc or ^{18}F disintegration, as appropriate. Subsequently, they were normalized by the measured total number of disintegrations during the irradiation. The latter parameters were obtained from measurements of the initial activities of radioactive solutions in a radioisotope calibrator and the irradiation times. The estimated uncertainty for the reference $H_p(0.07)$ values for ^{99m}Tc and for ^{18}F is equal to 10.5% and 8% (k=2), respectively. This uncertainty includes the component due to activity measurement (4.5% for k=2) and the simulation. The latter is calculated as the square root of the variance of the statistical uncertainty (2% for k=2) plus the variance associated with the simulated model (9.2% for ^{99m}Tc and 6% for ^{18}F, for k=2), which was estimated by

comparing the influence of different Monte Carlo codes and the geometry simplifications in the results.

2.3 Performance criteria

The analysis of the results is based on the general dosimetric requirements established by ICRP [19, 20]. The ratio between a measured dose value and the conventionally true value, (H_m/H_t) should be;

a) for a dose value equal to or approaching the annual limit: $1.5 \geq \left(\frac{H_m}{H_t}\right) \geq \frac{1}{1.5}$

b) for a dose value less or equal to the reporting level: $2.0 \geq \left(\frac{H_m}{H_t}\right) \geq 0$

The annual dose limit for the skin is 500 mSv. In some of the participating countries the recording level for $H_p(0.07)$ is 0.1 mSv and in others it is 1.0 mSv. For this analysis, the most restrictive value, 0.1 mSv, has been taken.

These two requirements are summarized considering that the ratio (H_m/H_t) is within the limits defined by the so-called "trumpet curves" [21, 22] and given by equations (3) and (4).

The upper limit is given by,

$$\left(\frac{H_m}{H_t}\right)_{upper\,\mathrm{lim}\,it} = 1.5\left(1 + \frac{H_0}{2H_0 + H_t}\right) \tag{3}$$

The lower limit is given by,

$$\left(\frac{H_m}{H_t}\right)_{lower\,\mathrm{lim}\,it} = \frac{1}{1.5}\left(1 - \frac{2H_0}{H_0 + H_t}\right) \tag{4}$$

where,
H_0 is the recording level for monthly monitoring (0.1 mSv in this work),
H_m is the participant measured dose value,
H_t is the reference dose value.

3. Results and discussion

Table 1 summarizes the main results of the intercomparison. It indicates, for each radiation field, the reference equivalent dose and its uncertainty (k=2), the mean response of the 24 participants, the response range of the participants (maximum and minimum response for each field), the number of services that fulfil the requirements (number of services with response within the trumpet curve limits).

The response of a participant, j, to a given radiation fie ld (Q_F), $R(Q_F,j)$ is defined as the ratio between the participant measured dose value and the reference dose value for this radiation field.

$$R(Q_F, j) = \frac{\frac{1}{2}\left(\sum_{i=1}^{2} L_{Q_F,j}(i)\right)}{H_{t,Q_F}} \tag{5}$$

The participant measured dose value for (Q_F) is estimated as the mean value of the two dosemeters exposed at this radiation field.

The mean response tabulated in the third column of table 1 is calculated as,

$$Mean\ \ response\,(Q_F) = \frac{1}{n}\sum_{j=1}^{n} R(Q_F, j) \qquad (6)$$

where, n is the number of participants, n=24 for ^{137}Cs and IR fields, and n=20 for beta qualities, ^{18}F and ^{99m}Tc.

Table 1: Summary of the intercomparison results for each tested radiation quality: reference dose equivalent dose and uncertainty (k=2), mean response, response range and number of services that fulfil the "trumpet curve" limits.

Radiation quality (Q_F)	$H_p(0.07)$ (± Uncertainty, k=2) (mSv)	Mean response	Response range	Number of services within the trumpet curve
^{137}Cs, 0°	4.5 ± 0.2	0.92	0.6 – 2.3	23/24
^{137}Cs, 60°	4.8 ± 0.2	0.91	0.4 – 2.2	22/24
^{137}Cs, 180°	5.2 ± 0.2	0.96	0.4 – 2.4	22/24
^{90}Sr-^{90}Y, 0°	8.2 ± 0.2	1	0.4 – 1.4	19/20
^{90}Sr-^{90}Y, 60°	9 ± 0.2	0.63	0.1 – 1.3	10/20
^{85}Kr, 0°	10.3 ± 0.2	0.45	0 – 1.2	8/20
^{85}Kr, 0°	11 ± 0.2	0.29	0 – 0.9	5/20
^{147}Pm, 0°	5.8 ± 0.2	0.25	0 – 1.2	5/20
^{147}Pm, 60°	8.3 ± 0.3	0.16	0 – 0.9	4/20
IR in beam	2.6 ± 0.2	1.86	0.5 – 12	21/24
IR outside beam	0.70 ± 0.05	1.86	0.5 – 11	21/24
^{18}F	10 ± 1	0.55	0.3– 1.1	7/20
^{99m}Tc	4.2 ± 0.3	1.08	0.6 – 2.3	19/20

Results show that, for ^{137}Cs, at all tested angles, with two exceptions, all reported doses are very close to 1. The average relative response is 0.93. For ^{90}Sr/^{90}Y, normal incidence, the results are also satisfactory except for one service. The average relative response is 1.00. The performance is worse at 60º, with an average relative response of 0.63 and only half of the services above the trumpet curve lower limit. For ^{85}Kr and ^{147}Pm, normal incidence, $H_p(0.07)$ is, in most cases, underestimated, the average relative responses are 0.45 and 0.25, respectively. Only dosimeters with thin filters and thin detectors provided appropriate results, 8 out of 20 for ^{85}Kr and 5 out of 20 for ^{147}Pm. Responses were even lower for the 60º angle of incidence.

There was a wide range of responses in the realistic interventional fields, from 0.21 to 12.5. Two services reported very high doses. One of them was the service who used CaF_2:Mn, that provided an acceptable response for ^{137}Cs, but that overestimated the dose for IR (R_{IR}=12), this was justified by the energy response of this type of TL material. The other one was the service that had a response of 2.35 for ^{137}Cs, thus highlighting that this participant had some problems with the calibration of the dosimetric system. Finally, one service underestimated significantly the given dose (R_{IR}=0.4). This result could also be due to a problem of calibration of the system since the response of this service for ^{137}Cs was 0.6 for a normal incidence and 0.4 for 60 º and 180º. The other 22 participants presented results within the limits. The average relative response was 1.86, taking into account the 24 participants but it was reduced to 1.29 if the two services with a large overestimation were excluded. It was shown that, generally, there was an overestimation of approximately 30% of the reported doses by the services that used LiF detectors and an underestimation of 15% for those that used $Li_2B_4O_7$.

The results obtained for the ^{99m}Tc irradiation were satisfactory in 19 out of 20 cases and the average relative response was 1.08. The service which did not fulfil the requirement is the one that used CaF_2:Mn, that, as mentioned before, is not suitable for other energies than the energy of calibration.

As regards the performance for ^{18}F irradiation, only 7 services out of 20 participants fulfilled the requirements. The average relative response was found to be 0.55, thus showing a general underestimation of the dose for this field. The 7 services, that performed satisfactorily, had also a good response for the reference beta field, ^{85}Kr, normal incidence. This result highlights that for PET applications, a dosemeter, with thin detectors and thin filter should be used.

The services were required to provide an estimate of their uncertainties in the assignment of doses. It was found out that the procedure to calculate the uncertainties and the components of the uncertainty budget varied substantially from one service to another. The uncertainties (k=2) ranged from 12 to 50%, when the energy dependence was included in the uncertainty budget, and, from 5 to 21%, when it was not. There is a clear need for harmonization in this field, and a need for many participants to review the calculation of their uncertainties taking into account the recommended components of uncertainty indicated in [21]. The energy response dependence in the fields of interest must, of course, be included in the uncertainty budget and its influence will be higher for non tissue equivalent detectors such as CaF_2:Mn. In Figures 1 and 2, we present the results of service 10 and 18, as an example. For each service, the figure includes the response, calculated as the ratio of the participant measured dose value and the reference value for each radiation field, Q_F, and the corresponding uncertainty (k=2). In this case equation (5) is not used since, every individual measurement is represented. The graphs also indicate the trumpet curves limit for each field, which are calculated from equations (3 and 4). Service 10 is one of the four services that obtained all the results within the trumpet curve limits and that included most of the uncertainty components in their calculations. Service 18 is an example of a participant which obtained results within the trumpet curve limits for ^{137}Cs, IR fields, ^{99m}Tc and ^{90}Sr/^{90}Y normal incidence, but underestimated the dose for the other fields. This is quite a typical behaviour of dosimeters with thick filter or detector. Figure 2 also points out, that in this case the reported uncertainty is clearly too small. Only 2 out of the 26 data points with the error bars show an overlap with the reference value.

Figure 1: Response of service 10 to the tested fields.

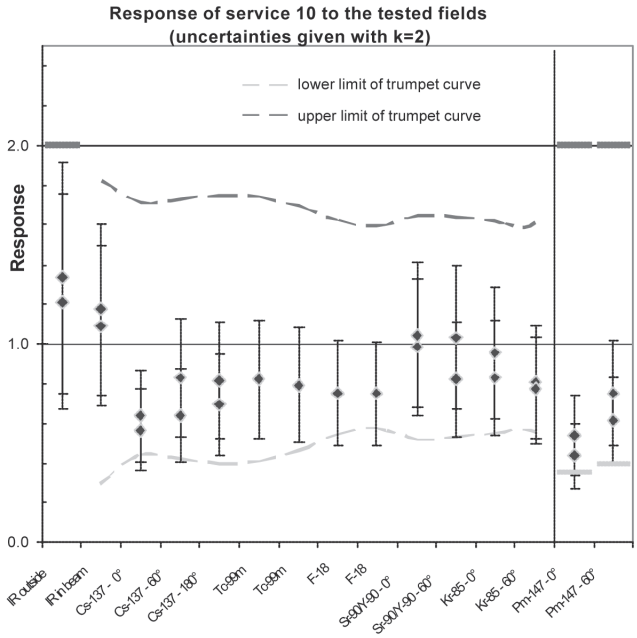
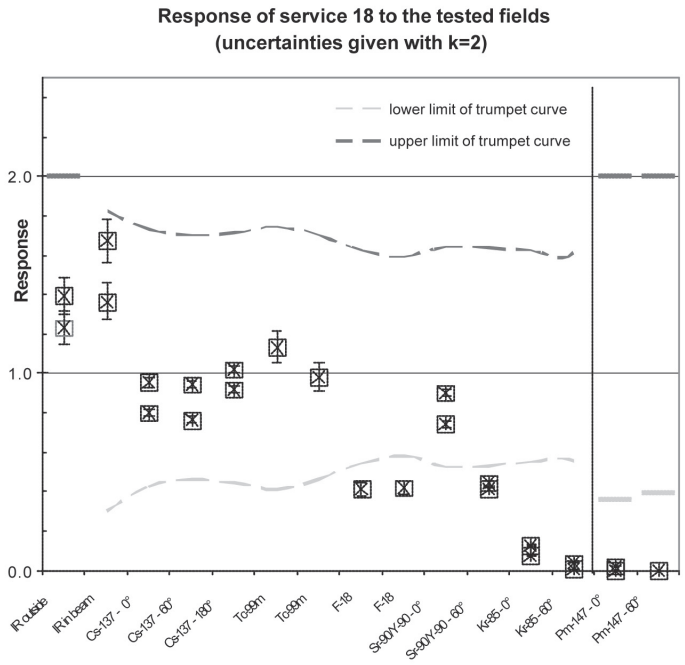


Figure 2: Response of service 18 to the tested fields.



4. Conclusion

This intercomparison highlights that extremity dosimetry can be used satisfactorily to estimate finger doses in typical medical fields, such as nuclear medicine and interventional radiology, where there is a potential risk of receiving high doses at extremities. However the study also points out that several services must review their procedures to improve their results. In particular it is shown than when the dosemeter is to be used for PET applications a thin detector capable of detecting beta radiation must be used. From the analysis of the results it can be concluded that a dosimetric service that fulfill ISO 12794 requirements for photon and beta radiation [23] will respond adequately to typical medical fields in interventional radiology, PET and conventional nuclear medicine. This standard does not include as a requirement the verification for ^{147}Pm. It must be indicated that some detectors were not supposed to be used in beta or mixed beta-gamma fields, and thus would be adequate for use in photon fields.

The results from the service that used CaF_2:Mn as detector material evidenced that this is not a good material to be used in medical fields, unless it is possible to introduce some type of energy correction.

Finally, the study showed that there was a need for harmonization among dosimetric services for the calculation of measurement uncertainty. The reported uncertainties ranged between 5% and 50% (k=2). In particular results confirm the need to estimate the contribution of energy response dependence on the measurement uncertainty.

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Guidelines for triage and monitoring of people exposed to radiation after a malevolent act

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Abstract. After an incident involving the malevolent use of radiation or radioactive material, the exposure could range from very low to substantial, possibly combined with conventional injuries. The European Commission through the Euratom 6th Framework Programme is co-sponsoring the specific targeted research project TMT Handbook, aimed at producing the practicable tools needed for an adequate response to such incidents. There is a wide range of published documents giving guidance. However, most of these documents give generic guidance that could be difficult to implement readily at the time of an incident. TMT Handbook will present practicable, concise advice in the form of a step-by-step guide for the effective and timely triage, monitoring and treatment of people exposed to radiation following a malevolent act. The handbook is divided into modules for various aspects of the response. One of the modules gives guidelines for best practice of triage and monitoring. Development of this triage and monitoring module is drawing on the internationally agreed practical guidance on the subject along with expertise from the project consortium and where appropriate, is making use of current practice in EU countries and existing IAEA and WHO publications. The module defines the monitoring procedures required to confirm a radiation emergency, describes procedures for defining the geographical area within which people may be affected, explains the initial triage and monitoring required for this affected population (including those with trauma injuries), describes how to define a monitoring strategy, and presents information on monitoring and dose assessment techniques. The draft of the handbook will be distributed to national emergency authorities and agencies for comments and they have been invited to test the modules in national emergency response exercises. The interaction with the end users on the practical application of the Handbook through the exercise programme will enable lessons to be learnt regarding implementation.

KEYWORDS: malevolent use of radiation, triage, monitoring, dose assessment.

1. Introduction

After an incident involving the malevolent use of radiation or radioactive material, the exposure could range from very low to substantial, possibly combined with conventional injuries. The European Commission through the Euratom 6th Framework Programme is co-sponsoring the specific targeted research project TMT Handbook, aimed at producing the practicable tools needed for an adequate response to such incidents. There is a wide range of published documents giving guidance. However, most of these documents give generic guidance that could be difficult to implement readily at the time

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of an incident. The module in the TMT Handbook giving guidelines on actions to be taken presents practicable, concise advice in the form of a step-by-step guide for the effective and timely triage and monitoring of people exposed to radiation following a malevolent act.

The triage and monitoring module is drawing on the internationally agreed practical guidance on the subject along with expertise from the project consortium and where appropriate, is making use of current practice in EU countries and existing IAEA and WHO publications.

The module defines the monitoring procedures required to confirm a radiation emergency, describes procedures for defining the geographical area within which people may be affected, explains the initial triage and monitoring required for this affected population (including those with trauma injuries), describes how to define a monitoring strategy, and presents information on monitoring and dose assessment techniques. This presentation is based on the draft version of the module which will be finalised in 2009.

2. Response actions

In the initial stages of the response, there will be little time to carry our detailed planning of the response, and minimal information on which to base such plans. Initial actions to be taken at the scene can be implemented automatically without the need to develop detailed plans that are specific to the incident.

After these initial actions are under way, there will be time to develop a monitoring strategy. This will take into account the specific characteristics of the incident, and of the information received as a result of the initial stages of triage and monitoring.

2.1 Triage

"Triage" is the use of simple procedures for rapidly sorting people into groups based on (a) their degree of physical injury and (b) on actual or potential effects on health, and the allocation of care to these people so as to expedite treatment and maximise the effective use of resources.

Triage is a fundamental part of the response to accidents (such as road traffic accidents) or natural disasters (floods, earthquakes, etc.). In such incidents, triage is designed to allocate medical treatment according to the urgency of the need of patients for care. The process is intended to maximise the number of survivors and can be termed "trauma triage".

Trauma triage may be required following incidents involving the malevolent use of radiation or radioactive material in a public place. However, the scope of triage is broader for such incidents and includes a group of actions that can be termed "radiological triage". These actions are intended to sort people rapidly into groups depending on actual or potential effects on their health resulting from radiation exposure.

Triage carried out following an incident involving the malevolent use of radiation of radioactive material is a multi-stage process that would be carried out over an extended period of time. A major problem will be to differentiate those needing care from the potentially large numbers of people who require only information and reassurance often known as the "worried well". In the early stages, triage decisions will have to be based on limited information, and will concentrate on the identification of those with an urgent need for treatment. In the later stages, more information (such as the results of initial monitoring) will be available, and triage will extend to the identification of groups requiring "low intervention" care.

In the Handbook the process of field triage in the event of an incident involving the malevolent use of radiation or radioactive material is described. Its scope includes all of the triage decisions made from the commencement of the incident up until the time when all people are correctly categorised for triage purposes (assumed to be about 6 days following the incident), or up to the admission of a

particular individual to hospital or other medical facility. The various stages and typical time periods in the field triage process are described in Table 1.

Table 1: The various stages in the field triage process

Triage Stage		Typical time period when triage decisions will be made	Information available
Trauma	Pre-monitoring	0-12 h	Severity of physical injuries to individuals
Radiological		2-36 h	Location, etc., at time of incident
		0 h – 6 days	Clinical signs and symptoms, and in the later stages, the results of complete blood counts
	Post monitoring	6-72 h	Results of initial screening measurements made at incident location
		12 h – 6 d	Results of measurements made with transportable *in vivo* monitoring facilities close to incident location
		24 h – 6 d	Results of laboratory *in vivo* monitoring measurements
		72 h – 6 d	Results of laboratory *in vitro* measurements of biological samples (e.g. radionuclides in urine, cytogenetic measurements of blood, etc.)

2.2 Monitoring

The term "monitoring" describes the measurement of radiation dose or contamination, for reasons related to the assessment or control of exposure to radiation or radioactive material, and the interpretation of the results. The monitoring carried our in response to an incident involving the malevolent use of radiation or radioactive material in a public place may be subdivided into source monitoring, environmental monitoring and individual monitoring. The TMT Handbook is mainly concerned with individual monitoring, but the other forms of monitoring also come within the scope of the Handbook.

Source monitoring is the measurement of activity in radioactive material released to the environment, or of external dose rates in the localised area around a source. In the present context, its main objective are to indentify and locate the source, and evaluate its potential for exposing people to radiation or radioactive material.

Environmental monitoring is the measurement of external dose rates arising from a source in the environment, or of radionuclide concentrations in environmental media. In the present context, its main objective is to determine the geographic distributions of dose rates and/or levels of contamination.

Individual monitoring is monitoring using measurements of quantities of radioactive material in or on the body of the individual, or measurements made by equipment worn by individual workers. It includes the assessment of radiation doses to the individual from the results of measurements.

2.2.1 Monitoring to confirm a radiation emergency

It has to be established whether or not the incident involves the use of radiation of radioactive material, to establish whether radioactive material has been dispersed through the environment and to establish approximately those areas where dose rates or levels of contamination are highest.

Priorities and actions will differ according to the scenario. In the module the following scenarios are considered:

- irradiation (irradiation incident)
- environmental contamination (contamination incident)
- contamination of food/water

2.2.2 Environmental Contamination (Contamination) and External Irradiation (Irradiation) Incidents

For these types of incidents monitoring teams should be established. These teams are likely be made up from staff from first responder organisations (e.g. fire service) or of specialist radiation protection staff. It is unlikely that emergency services will have the equipment or experience to monitor for all types of radiation. Emergency services staff required to do emergency monitoring must, as a minimum, be able to identify elevated gamma dose rates. If only gamma-dose rate monitoring is available then it must be assumed there is widespread contamination of the environment, until contamination monitoring has been carried out.

2.2.3 Monitoring Instruments

The following is a list of instrument types which may be useful for confirming the presence of specific radiation types or to identity the radionuclide(s) present:

- alpha contamination monitors
- beta dose rate monitors
- beta contamination monitors
- X-ray and low energy gamma contamination monitors
- Gamma dose rate monitor
- portable gamma-spectrometry equipment.
- Neutron dose rate monitor

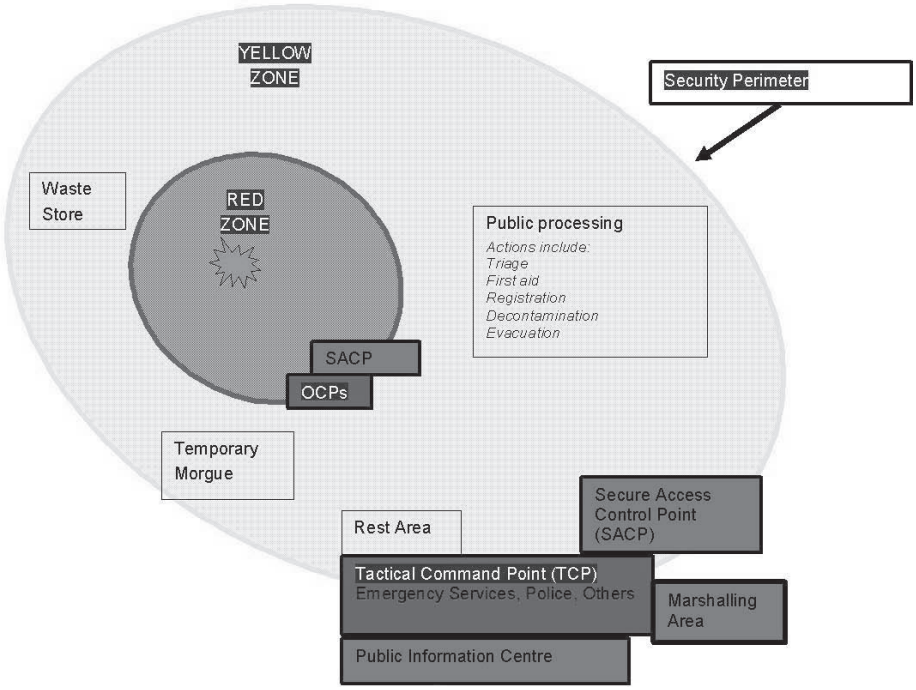
3. Zones and Reception Centres

Zones are established around the scene of an incident to protect and control the public, protect and control members of the emergency services, facilitate the operations of all agencies, guard the scene and prevent unauthorised interference with evidence or property. The Red Zone is the potentially hazardous area immediately surrounding the incident where extreme caution and safety measures is required. The cordon surrounding this zone is called the ‘Safety Perimeter’. The Yellow Zone surrounds the Red Zone and provides a safe and secure working environment for personnel and members of the public being processed for clearance from the incident. The cordon surrounding this zone is called the ‘Security Perimeter’.

A reception centre is set up where people not requiring urgent medical treatment following an emergency can be sent for shelter, rest and medical treatment. There information from affected individuals can be collected, they can be informed and counselled. It is expected that people evacuated

from within the security cordon should be directed to the Reception Centre. People returning having left the scene would also be directed to the Reception Centre.

Figure 1: Generic layout of zone boundaries



3.1 Radiation Monitoring Unit

Associated with the reception centre a radiation monitoring unit may be established. This may be located in the same building as the reception centre of located in a separate nearby building. People should be monitored at the radiation monitoring unit and if necessary decontamined, before entering the Reception Centre.

The radiation monitoring unit should have a segregated area for people waiting for decontamination, an area for external contamination measurements, an area for decontamination of people and an area for internal contamination monitoring (if available). Also available should be storage for replacement clothing, storage for contaminated clothing and other contaminated items, an area for recording and reporting information with communications equipment and an area for counselling concerned individuals.

3.2 Individual Monitoring Methods

The primary monitoring method is the method that is expected to provide the most reliable assessment of internal dose. The measurement is likely to be carries out in a laboratory. For most radionuclides, more rapid measurements can be carried out in the field, although these will in general be less accurate. Such measurements are of most use for triage purposes, and are referred to as *rapid screening methods*. The initial survey can be done with hand held scintillation probes or dose rate monitors without any knowledge of the radionuclides involved. Portable or transportable body monitors are useful for body counting as demonstrated in figures 1 and 2. If *in vivo* monitoring facilities are not available or the radionuclide(s) cannot be detected directly from outside the body, indirect methods can be employed. Samples of urine, faeces, blood, nasal swabs, saliva can be used.

In an accident situation it is often not possible to reconstruct reasonably the absorbed dose on the basis of physical dosimetry, and biodosimetry might be the only option to characterise the casualty exposure. In table 2 some rapid screening and primary monitoring methods for a number of radionuclides.

Figure 2: Thyroid measurement with NaI(TI) detector

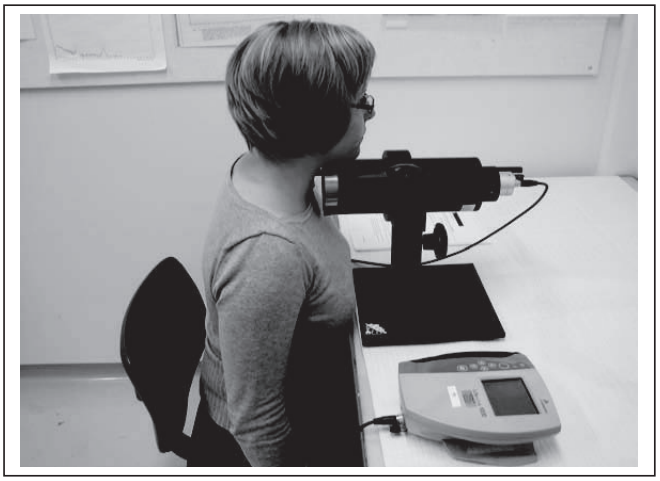


Figure 3: Gammaspectrometric body measurement in lap geometry

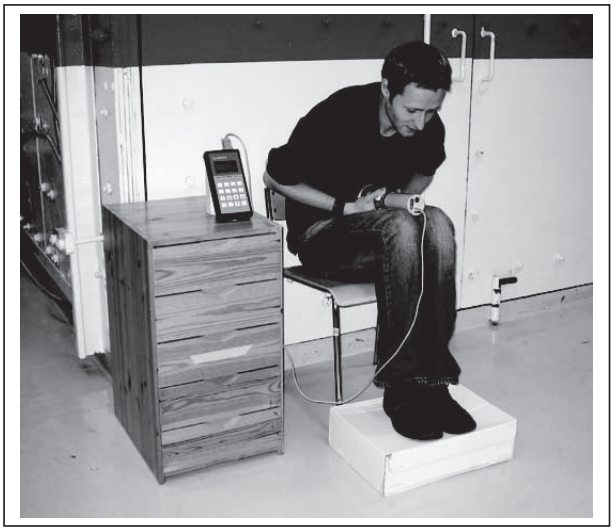


Table 2: Rapid screening and primary monitoring methods for some radionuclides.

Radionuclide		Radiation type	Rapid screening method	Primary monitoring method
Cobalt-60	^{60}Co	β, γ	Whole body (rapid)	Lung
Strontium-90	^{90}Sr	β	Nose blow	Urine
Barium-133	^{133}Ba		Whole body (rapid)	Whole body
Caesium-137	^{137}Cs	β, γ	Whole body (rapid)	Whole body
Polonium-210	^{210}Po		-	Urine
Radium-226	^{226}Ra		Nose blow	Lung, Urine
Plutonium-238	^{238}Pu		Nose blow	Urine, Faeces (Lung)
Americium-241	^{241}Am	, γ	-	Lung

The purpose of the initial screening, with field survey equipment, is to classify people according to their levels of internal contamination, as a guide to decisions on further action. The preliminary screening and classification should be performed in an area appropriate to the potential demand, and large enough to permit adequate separation between people awaiting initial monitoring, those being monitored, those awaiting transfer for further assessment and space for temporary collections of contaminated clothing. Public facilities such as sports centres and arenas are likely to be suitable for large groups of people.

4. Registration of people and recording and reporting of results

Registration of people involved in incidents should give unambiguous identification of the person monitored or of samples collected. The purpose of record keeping, the nature and scope of the records, and the extent of record keeping systems depend on national requirements. The records should include the results of individual monitoring for internal contamination from both direct and indirect measurements. Models for emergency registration forms are included in the TMT Handbook.

After an incident the first report is needed as soon as possible (within 24 hours) to be used by the "emergency preparedness authorities" for decision making. At the stage the dose assessment might be very preliminary.

The report should include information on type of measurement (environmental, direct or indirect on persons), dose rates, in case of sample type and time of collection, analysis method and results obtained. Within a week a more reliable report will be needed to be used by health and other authorities for further decision making.

The procedures and levels to be used for reporting individual monitoring results should be clearly specified by the management or regulatory authorities. Information reported should be clearly identifiable and understandable. If only final results are reported results which fall below the MDA or derived recording level may be reported as such. (However, the actual result, along with its

uncertainty, should be retained in the records.) Because of privacy considerations, reports should be safeguarded and the persons identity protected, as for medical records.

5. Summary

The handbook contains both general information and detailed proposals for actions to be taken at the scene and in the hospitals by specialized teams in radiation protection, monitoring and medical treatment. It is intended to be used during the response to an incident as a source of practicable guidance. It is believed that this Handbook will help Emergency Response Organisations to prepare for response in case of malevolent use of ionising radiation. The above presentation is a short overview of one of the modules in the Handbook. In addition to the contents in the modules more information is collected into annexes most useful for planning of emergency response.

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ESTIMATING POPULATION DOSES FROM MEDICAL RADIOLOGY

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Abstract. An EU-funded project called DOSE DATAMED has been set up to develop mutually acceptable methods for future surveys of population exposure from medical x-rays, including issuing guidance on suitable patient dose quantities and dosimetry methods. The second report from the project group deals with guidance on how to conduct population dose surveys for medical exposures to improve the comparability of results from various countries. In order to assess population exposures from medical radiology in terms of the collective or per caput effective dose, it is necessary to estimate representative mean effective doses for each type of x-ray examination that makes a significant contribution to the collective dose in a country. Suitable practical dose quantities are entrance surface dose or the dose-area product for simple radiography, the total dose-area product for examinations including fluoroscopy, and the computed tomography dose index and the dose-length product for CT examinations. Factors for converting these practical dose quantities into effective doses are provided in the report. Guidance on assessing the frequency of x-ray examinations includes the definition of 225 specific x-ray examinations and 70 broader categories of examinations, and the identification of those 20 examinations most contributing to the collective effective dose. Information on the age and sex distribution of the patients undergoing these 20 important examinations is provided to assist in relating the collective doses to the collective detriment. Simple approaches for those countries that do not have resources to make comprehensive frequency or dose surveys are provided. The uncertainties involved in various survey methods are addressed. New approaches using dose data stored in the DICOM header and information in the radiological information system (RIS) are also discussed.

KEYWORDS: Diagnostic x-rays, patient dose, dosimetry, population exposure

1. Introduction

The European Commission (EC), on advice from the Article 31 Group Working Party on Medical Exposures, instigated a study at the end of 2004 to review the current situation in Member States regarding the implementation of Article 12 of the Medical Exposure Directive of 1997 and to develop appropriate guidance [1]. Article 12, entitled 'Estimates of population doses', requires Member States to ensure that the distribution of individual dose estimates from medical exposure is determined for the population and for relevant reference groups of the population, as may be deemed necessary by the Member State. The Commission was concerned that there were no internationally accepted protocols for evaluating patient exposures from medical x-ray imaging procedures and that reported estimates of population doses varied widely between European countries with similar levels of healthcare. It was thought that some of this variation might be due to differences in the methodology adopted to assess

population doses between Member States and to large inherent uncertainties in these assessments that had not been fully evaluated.

A multinational project (called DOSE DATAMED) involving ten European countries was set up to carry out this study. All project partners and the institutes that they work for have long experience of conducting national surveys of population exposure from medical radiology. The project has built upon this experience to review the existing national arrangements and strategies for carrying out these surveys in each country. It has looked at the different healthcare systems operating in each country to see if they could account for some of the differences observed in the population doses. It has studied and compared the methods and results of the most recent population dose surveys in each country and evaluated the uncertainties. The first report from the group (DD Report 1) presents the results and conclusions from this review of recent national surveys of population exposure from medical x-rays in Europe. A supplementary report - DD Report 1(a) - provides a brief review of the methods and results of recent national surveys of population exposure from diagnostic nuclear medicine procedures in eight of the DOSE DATAMED countries. The second report from the group (DD Report 2) provides recommendations for the development of a harmonised system for assessing patient doses and the level of provision of diagnostic radiology services in Member States, in order to improve the comparability of national population dose estimates in the future. In view of the relatively low contribution of nuclear medicine to population exposure compared to medical x-rays (4-14% in the various DOSE DATAMED countries), and the more straightforward and well-established methods for assessing patient doses for nuclear medicine examinations (see DD Report 1(a)), this guidance concentrates on population dose assessments for the x-ray imaging procedures used in diagnostic and interventional radiology. Nonetheless, much of the guidance given on the assessment of the frequency of x-ray procedures can be equally applied to nuclear medicine examinations.

This paper provides a summary of the recommendations from the DOSE_DATAMED project (2003 – 2007). The report "G*uidance on Estimating Population Doses from Medical Radiology"* has been approved by the Commission in working party meeting 23/24 April 2008, and will be published as an EC Report in the 'RADIATION PROTECTION' series on the EC DGTREN Radiation Protection website http:/ec.europa.eu/energy/nuclear/radioprotection/publication_en.htm as a pdf file.

2. Summary of recommendations

2.1 Purposes of population dose estimates, desired frequency and resources required

- The objectives of the study need to be clearly stated in any report on population doses from medical radiology. These might include all or only some of the following objectives:
    1. To observe trends in the annual collective dose (or the annual average per caput dose) from medical x-rays in a country with time.
    2. To determine the contributions of different imaging modalities and types of examination to the total collective dose from all medical x-rays.
    3. To determine the relationship between the frequencies of different types of x-ray examination, the typical radiation doses given to patients and their contribution to the total collective dose.
    4. To determine whether there are any regional variations within a country in the frequency or collective doses from particular types of x-ray examination.
    5. To compare the frequencies and the annual per caput doses from medical x-rays between countries.
    6. To compare the contribution from medical x-rays with those from other natural and man-made sources of population exposure in a country.
    7. To determine the age and sex distribution of the patients undergoing specific types of x-ray examination, particularly those making a major contribution to the total collective dose.

- If objective 6 or any additional objectives that involve comparisons of the radiation risks from medical radiology with those from other sources of population exposure are being considered, the

serious limitations of collective effective dose in this regard should be declared and objective 7 becomes particularly important.

- It is recommended that, if possible:
  - Frequency surveys should be repeated every 5 years
  - Patient dose surveys should be repeated every 5 years
  - Both types of survey should be as close in time as possible

  although it is recognised that the resources required to perform these surveys are considerable and not every country may be able to meet this ideal.

- At least two senior scientists, should be responsible for co-ordinating the whole project and to assure the scientific quality of the results

- The team conducting the survey should have expertise (internally or by external consultancy) in radiology, dosimetry, public health, statistics and project management.

- National public health and the radiation protection authorities should be involved in the project.

- Collaboration with the professional bodies associated with medical radiology is essential from the first stage of the survey.

2.2 Suitable dose quantities

- The annual collective and per caput effective doses for the totality of all x-ray examinations conducted in a country and for those specific examinations making major contributions to the total should be estimated, to meet objectives 1-5.

- In addition, information on the age and sex distribution of the patients undergoing the types of x-ray examination making a major contribution to the total collective dose will be valuable for relating the collective doses to the collective detriment (important for objective 6).

- Effective dose estimates for medical exposures should **not** be used for assessing radiation risks to patients by simple application of ICRP's nominal probability coefficients for radiation-induced cancer.

2.3 Guidance on assessing frequency of x-ray examinations

- An x-ray examination or interventional procedure should be defined as:
  '*One or a series of x-ray exposures of one anatomical region/organ/organ system, using a single imaging modality (i.e. radiography/fluoroscopy or CT), needed to answer a specific diagnostic problem or clinical question, during one visit to the radiology department, hospital or clinic*'.

- The most reliable and accurate approach is to collect frequency data (and estimate typical effective doses) for every specific type of examination.

- The second best approach is to collect frequencies (and estimate doses) for broad categories of examinations.

- The third best approach is to give priority to the examination types and categories that contribute most to the collective effective dose in the country, covering at least 75% of the total. If a country does not have the resources to investigate and identify the procedures that are currently responsible for 75% of the collective dose, the 'Top 20 Exams' listed in Table 1 (and described in detail in Appendix 1 in the report) can be used.

Table 1: The twenty examination types identified to be the highest contributors to the collective effective dose in Europe

Plain film radiography (no contrast medium)	Radiography/fluoroscopy (usually with contrast)	Computed tomography	Interventional radiology
1. Chest	8. Barium meal	13. CT head	20. PTCA
2. Cervical spine	9. Barium enema	14. CT neck	
3. Thoracic spine	10. Barium follow	15. CT chest	
4. Lumbar spine	11. IVU	16. CT spine	
5. Mammography	12. Cardiac angiography	17. CT abdomen	
6. Abdomen		18. CT pelvis	
7. Pelvis and hips		19. CTentire trunk	

- Annual numbers of examinations can be obtained directly from a sample of hospitals, clinics or practices and then scaled up to cover the whole country; or from central statistics held by government departments or insurance companies for all (or at least a large proportion) of radiology practice in the country.

- Information on the annual numbers of x-ray examinations should be available from the computerised Radiology Information Systems (RIS) that are now widely in place in most hospitals throughout Europe.

- If frequency data are derived from a relatively small sample of hospitals or practices, steps should be taken to ensure that the sample is as representative of national radiology practice as possible.

- It is important to make clear whether dental radiology conducted by dentists in 'Dental Practices' and/or Nuclear Medicine examinations are included in the population dose assessments or not.

- Major sources of error in the frequency estimates should be identified and the uncertainties evaluated. Important sources of uncertainty include:
    - Problems in relating the information stored in terms of examination codes into actual numbers of examinations
    - Bias in the sample and invalid assumptions made when scaling up sample data to derive frequencies for the whole country
    - Lack of frequency data from some important providers of radiology services
    - Mistakes in the data recorded or collected

2.4 Guidance on assessing patient doses

- Medical physicists with particular expertise in diagnostic radiology dosimetry should be directly involved in the assessment of patient doses.

- In order to assess population exposures from medical radiology in terms of the collective or per caput effective dose it is necessary to estimate representative mean effective doses (E) [2, 3], for each type of x-ray examination that makes a significant contribution to the collective dose in a country.

- The most reliable and accurate approach is to conduct extensive patient dose surveys to measure or calculate practical dose quantities at as representative a sample of hospitals in a country as possible.

- The practical dose quantities that are commonly measured include the entrance surface dose (ESD) or the dose-area product (DAP) for simple radiography, the incident air kerma (K_{ai}) for

mammography, the dose-area product (DAP) for radiographic/fluoroscopic examinations, and the computed tomography dose index (CTDI) and the dose-length product (DLP) for CT examinations.

- The number of hospitals and clinics included in the survey must be large enough to reflect all variations in clinical practice in the country

- The number of rooms included from each hospital and the selection of hospitals must be such that they reflect all types of x-ray equipment used for a certain examination type in the country

- For the purpose of making population dose estimates, it is reasonable to assume that children receive the same mean effective dose as adults from the same type of examination.

- When measuring doses directly on patients, the sample of patients in each room/facility should be representative regarding their size (weight) and the clinical indication. Ideally doses should be measured or calculated for at least 10 and preferably 20 close-to-average size adult patients (e.g. with weights between 60–80 kg). No complication leading to higher than usual doses or no premature termination of the examination should have occurred.

- When doses are measured or calculated for a standard examination protocol, the protocol should be representative for the average "typical" procedure used in each room/facility for average sized adult patients.

- When selecting coefficients for converting practical dose measurements into effective doses, those which most closely match the exposure conditions and examination techniques for the examinations in question should be used.

- If it is not possible to derive conversion coefficients matched specifically to the exposure factors and examination techniques used in a particular country, generalised coefficients may be used.

- For those countries currently without the resources to make extensive national patient dose surveys, three sets of 'typical' effective doses for the 'Top 20 Exams' are provided in the full report. Such countries should choose the set that is derived from the DOSE DATAMED countries in which the healthcare setting most closely matches their own.

- Major sources of error in the typical effective dose estimates should be identified and the uncertainties evaluated. Important sources of uncertainty include:
    - Uncertainties in the basic dose measurements
    - Uncertainties due to variations in patient doses between hospitals and the limited sample size
    - Uncertainties in the coefficients used to convert the measured dose quantities into typical effective doses

- The new tissue weighting factors recommended in the 2007 recommendations of the ICRP [3] are likely to result in significant increases in effective doses calculated for x-ray examinations of the head and breast and significant reductions for examinations of the pelvis. Consequently, care must be taken when comparing new and old effective dose estimates, not to confuse changes due to the use of different tissue weighting factors with changes due to differences in radiology practice.

- In the future when voxel phantoms are used to derive improved organ and effective dose conversion coefficients for diagnostic medical exposures, care must be taken when comparing new and old effective dose estimates, not to confuse changes due to the use of different phantoms with changes due to differences in radiology practice.

2.5 Guidance on assessing age/sex distributions of x-ray patients

- When the objectives of making a population dose estimate include comparisons of the contribution from medical x-rays with those from other natural and man-made sources of population exposure in a country, it is important to determine the age and sex distribution of the patients undergoing important types of x-ray examination.

- Ideally, the age and sex distribution of patients undergoing those types of x-ray examination making a major contribution to collective dose should be determined in each country by a representative survey of national practice.

- Ideally, the data for each type of examination should be presented in five year age bins for each sex.

- If specific national data are unavailable, typical European age/sex data for the 'Top 20 Exams' and for 'All CT, 'All angiography' and 'All interventional' procedures, based on the average distributions seen in five DOSE DATAMED countries, can be used. These are shown in Appendix 3 in the report.

2.6 Guidance on presenting the results of population dose estimates

- Clearly state the objectives of the study, the period over which data was collected and whether it covers all significant types of radiology practice in the country or not.

- Essential information to report:
  - Total annual collective effective dose from all medical x-ray imaging procedures
  - Total annual average per caput effective dose from all medical x-ray imaging procedures
  - Total annual numbers of all medical x-ray imaging procedures
  - Total annual numbers of all medical x-ray imaging procedures per 1000 population
  - Mean effective dose per procedure (averaged over all medical x-ray imaging procedures)

  - Same data as above but broken down into:
    - All CT examinations
    - All angiographic examinations
    - All interventional procedures
    - All radiographic and fluoroscopic diagnostic x-ray examinations not included in above 3 categories

  - List those types of examination or procedure responsible for at least 75% of the collective dose.
  - Give percentage contribution to the total frequency and the total collective dose and the mean effective dose estimated for each of these examinations/procedures.

- Desirable information to report:
  - Same data as above but 4th category further divided into:
    - Radiography of the teeth
    - Radiography of the chest
    - Radiography of the limbs
    - Radiography of the spine
    - Mammography
    - Radiography/fluoroscopy of the gastro-intestinal tract
    - Radiography/fluoroscopy of the urinary tract
    - Other radiography/fluoroscopy

- Ideally, the age/sex distributions of the patients undergoing the major contributors to the collective dose should be determined from a representative sample of patients in the country.
- If this is not possible, the typical European age/sex distributions shown in Appendix 3 of the report, and based on the average distributions seen in the DOSE DATAMED countries can be referred to.

2.7 Use of electronic information stored in modern medical imaging and radiology information systems

- The need for compliance with the latest standards of the International Electrotechnical Commission (IEC) and profiles from Integrating the healthcare Enterprise (IHE) for radiation dose reporting in radiology should be included in purchasing specifications for new x-ray equipment or new radiological information systems (RIS) or Picture Archiving Systems (PACS).

- In the future the national authorities responsible for population dose surveys may gather the electronic information on patient doses from RIS/PACS systems around the country as input to any national dose databases for the establishment of diagnostic reference levels and/or for future population dose estimates.

Acknowledgements

The DOSE DATAMED working group would like to express gratitude to the Commission for the opportunity to put this subject on the agenda, and to our respective employers for supporting our efforts.

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RECENT NATIONAL SURVEYS OF POPULATION EXPOSURE FROM MEDICAL X-RAYS IN EUROPE

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Abstract. An EU-funded project called DOSE DATAMED (2004 – 2007) has been set up to develop mutually acceptable methods for future surveys of population exposure from medical x-rays, including issuing guidance on suitable patient dose quantities and dosimetry methods. In the first report from the project group, recent national surveys in ten European countries have been reviewed in order to explain the significant differences seen in examination frequencies and patient doses, and their mutual influence on the collective effective dose (S) per year in each country. A set of 20 examinations are identified as the ones contributing most significantly to S, and therefore important to focus on for other countries planning to do similar population dose surveys. The national regulatory frameworks, the health care systems, the methods for assessing frequency and doses, as well as the national strategies for assessing population dose from medical x-rays, have been reviewed. As a conclusion, the observed differences in the population dose from medical x-rays in Europe are thought to be real, i.e. much larger than the recognized uncertainties originating from the survey design. Furthermore, the differences were found to be primarily due to the different healthcare systems operating in each country, which resulted in considerable variations in the amount of equipment and manpower devoted to medical radiology and in the financial incentives for carrying it out.

KEYWORDS: Dose surveys, diagnostic x-rays, patient dose, dosimetry, population exposure

1. Introduction

The European Commission (EC), on advice from the Article 31 Group Working Party on Medical Exposures, instigated a study at the end of 2004 to review the current situation in Member States regarding the implementation of Article 12 of the Medical Exposure Directive of 1997 and to develop appropriate guidance [1]. Article 12, entitled 'Estimates of population doses', requires Member States to ensure that the distribution of individual dose estimates from medical exposure is determined for the population and for relevant reference groups of the population, as may be deemed necessary by the Member State. The Commission was concerned that there were no internationally accepted protocols for evaluating patient exposures from medical x-ray imaging procedures and that reported estimates of population doses varied widely between European countries with similar levels of healthcare. It was thought that some of this variation might be due to differences in the methodology adopted to assess population doses between Member States and to large inherent uncertainties in these assessments that had not been fully evaluated.

A multinational project (called DOSE DATAMED) involving ten European countries was set up to carry out this study. All project partners and the institutes that they work for have long experience of conducting national surveys of population exposure from medical radiology. The project has built upon this experience to review the existing national arrangements and strategies for carrying out these surveys in each country. It has looked at the different healthcare systems operating in each country to see if they could account for some of the differences observed in the population doses. It has studied and compared the methods and results of the most recent population dose surveys in each country and evaluated the uncertainties. The first report from the group (DD Report 1) presents the results and conclusions from this review of recent national surveys of population exposure from medical x-rays in Europe. This paper summarizes and gives examples from the DD report 1, with emphasis on the identification of the "top 20" examinations most contributing to the collective effective dose (S), and the reasons for differences between the ten DOSE DATAMED countries in S.

2. Materials and method

2.1 How to collect information on examination frequency and patient doses

The most recent surveys in ten European countries, most of them already published in the open literature [2 – 16], have been reviewed in order to explain significant differences seen in examination frequency and patient doses and their mutual influence on S. In the frequency surveys the year of counting ranged from 1995 to 2002 between the ten countries. The collected data were either based on information from licence holders or from health insurance companies. Differences were identified in how the examinations were classified or coded; from 18 broad categories of examinations to more than 250 specific procedures. The data were usually based on just a part of the population and therefore had to be scaled up for the whole country. The information on patient doses in the ten European countries came from measurements from 1985 to 2005. In X-ray radiography and fluoroscopy most countries based their dosimetry on the dose-area product (DAP) or to some extent the entrance surface dose (ESD). In CT the usual method was to collect information on the CTDI free in air together with scan protocols from the licence holders, and to use Monte Carlo conversion coefficients and available software to calculate the effective dose.

2.2 Uncertainties in collective effective dose estimates

The national figure for the total S from diagnostic use of radiation is subject to uncertainties in both frequency and dose for each of the X-ray based examinations. The uncertainties in the estimate of examination frequency are due to

a) problems in relating the information stored in terms of examination codes into actual numbers of examinations (e.g. inadequate definition of an "examination", problems of double-counting, particularly with examinations of double-sided organs),

b) insufficiently differentiated codes,

c) bias in the sample and invalid assumptions made when scaling up sample data to derive frequencies for the whole country (i.e. problem of using data from an unrepresentative sample of hospitals or from incomplete central statistics),

d) lack of frequency data from some important providers of radiology services,

e) mistakes in the data recorded or collected.

The uncertainty in the dose value for a certain examination type also depends on several factors such as

a) the basic dose measurements,

b) the coefficients used to convert the measured dose quantities into typical effective doses

c) the variations in patient doses between hospitals,

d) the limited sample size.

The project group developed a pragmatic method for estimation of the uncertainty in the assessment of S, and tested this method for three countries (DE, NO, UK). The exercise was only done for twenty examination types, but these were the identified examinations that contributed to between 70 – 90% of S in the DOSE DATAMED countries. The method was based on the following assumptions:

- The relative random and systematic errors in frequency were estimated for each of the 20 examination types according to the various sources of uncertainty mentioned above, variance and scaling (in the range 2.5 % - 110%). The total and relative uncertainty was calculated as the root mean square sum of the single sources of uncertainty.
- The relative uncertainty in patient dose estimates was set in the order 10 – 25% depending on the sample size (number of X-ray rooms) combined with the uncertainty in the order 10 – 25% due to good or poor matching of exposure conditions in the conversion coefficient calculations. The overall uncertainty in the national patient dose estimates were then in the range 14 – 56%. If foreign data were used in the assessment the overall uncertainty was set in the range 50 – 100%
- The relative uncertainty in S was calculated as the root mean square sum of the uncertainty in frequency and dose respectively.

2.3 Parameters that may explain differences in the collective effective dose

The national health care system and regulatory framework in the ten European countries were studied to explain differences in examination frequency and dose. Information on a set of parameters that were believed to have some influence on the use of X-rays were collected, such as the % of Gross Domestic Product devoted to health care, the quantity of X-ray equipment and the number of medical doctors, dentists, radiologists and others who use X-rays (e.g. cardiologists, gastroenterologists, urologists, lung specialists, orthopaedic surgeons, vascular surgeons). Information on the referral system, reimbursement system and radiologist payment system was also gathered. All this information was used as background for qualitative comparison and discussion.

3 Results

3.1 Basic data for national surveys of population doses from ten European countries

The basic survey methods and most recent results from the ten DOSE DATAMED countries are summarized in Table 1. The examination frequencies are shown in Figure 1 for a) all medical X-rays except dental and b) dental X-rays separately.

Figure 1: Total annual number of medical x-ray examinations performed per thousand populations in ten European countries

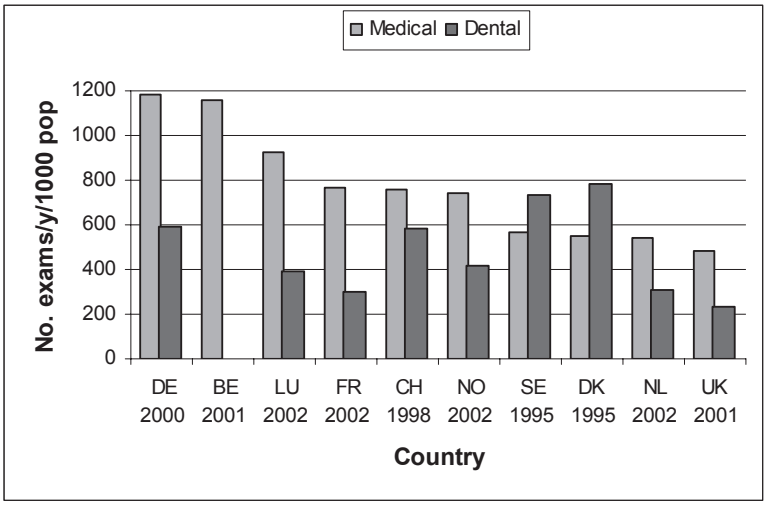


Table 1: Basic data for national surveys of population doses from ten European countries

	UK	CH	NL	DE	FR
Survey Dates					
Date (frequency)	2001	1998	2002 ('90)	2000	1999-2002
Date (doses)	1990-2001	1998	2002 ('90)	1992-2005	2001-2003
Population	60 million	7.1 million	16 million	82.3 million	61.4 million
Methods					
Basic freq. data	Annual nos from 38 trusts in 2 different regions (16% of English exams)	Annual nos from 11 big hospitals. 2 week survey in 274 medium & small hospitals & 2787 practices	Annual nos from 90% of hospitals	Annual nos from health insurance (statutory + private) for about 80% of x-ray exams	Annual nos from health ins + stats of Health Estabs. 1999 - conv x-rays 2002 - CT & dental
Scaled up to whole country by	Total no. of x-ray exams per trust	No. of hospitals & practices with x-ray unit	No. of hospital admissions	Scaling factors to estimate in-patient data (2002 in-patient data available)	No scaling necessary
No. of exam types	Freq: 150 Dose: 150	Freq: 257 Dose: 257	Freq: ~18 broad categories Dose: 48	Freq: 90 Dose: 40	Freq: 110 Dose: 8
Age/sex data (yes/no)	No	Yes	Yes (for 2000)	Yes (in-patients)	No
Basic dose data [1]	ESD, DAP, CTDI from large UK surveys	ESD calculated from av. Swiss technique factors. CTDI values for Swiss CT scanners from literature.	ESD, DAP, CTDI (measured in 11 hospitals)	ESD calculated from technique factors. DAP (in selected hosps). CTDI, DLP (from national survey)	ESD, CTDI, DLP from DRL campaign
Source of E coefficients [2]	NRPB-R262 (r/fl) NRPB-R250 (CT)	ODS-60 (r/fl) CT-Dose (Danish)	PCXMC (r) NRPB-R262 (fl) NRPB-R250 (CT)	GSF 11/90 (r/fl) NRPB-R262 (r/fl) GSF 30/91 (CT)	NRPB-R262 EUR 16262 (CT)
Results					
Total no. exams/y (incl. dentists)	43 million	9.5 million	13.7 million	146 million	59–72 million [3]
Total no. exams/y (excl. dentists)	29 million	5.4 million	8.7 million	97.6 million	41-53 million
Total no. exams/y/1000 pop (incl dentists)	716	1343	847	1775	964 – 1173 [3]
Total no. exams/y/1000 pop (excl dentists)	483	762	538	1187	664 – 873 [3]
Total no CT/y/ 1000 pop	30	46	37	89	68 – 98 [3]
Annual S from all exams (man Sv)	22.700	7100	7300	136.200	40.400 – 50.700 [3]
Total annual S /head (μSv)	**380**	**1000**	**450**	**1656**	**602 - 770 [3] [Av = 686]**
CT annual S /head (μSv)	**178 (47%)**	**280 (28%)**	**190 (42%)**	**721 (43%)**	**238 - 338 [3] [Av = 285] (42%)**
References	[2, 3]	[4, 5]	[6, 7]	[8, 9]	[10]

Table 1 (continued): Basic data for national surveys of population doses from ten European countries

	NO	SE	LU	BE	DK
Survey Dates					
Date (frequency)	2002	1995	2002	1996-2002	1995
Date (doses)	1985-1995	1995	-	2000 -2005	1995
Population	4.6 million	8.8 million	430,000	10.2 million	5.1 million
Methods					
Basic freq. data	Annual nos from all hosps & clinics (excl. dentists)	Annual nos from licence holders covering 25% of population.	Annual nos from Nat Health Ins (99% survey)	Annual nos from Nat Health Ins Inst (97-100% survey)	Directly from national hosps. Chiro–39 clinics (95% survey)
Scaled up to whole country by	No scaling necessary	Multiply by 4	No scaling necessary	No scaling necessary	Multiply by 1.05
No. of exam types	Freq: 250 Dose: 54	Freq: 15 Dose: 15	Freq: 250	Freq: ~130 Dose: ~15	Freq: 118 Dose: 118
Age/sex data (yes/no)	No	Yes (Age: 0-15, 16-40, >40)	Yes (5y bins)	Only CT (0-15, 10y bins, >85)	Yes (10y bins)
Basic dose data [1]	DAP, CTDI (national surveys)	DAP, CTDI (measured in local hosps - 6% of licence holders)	No measurements	ESD, DAP (measured in 37 centres)	DAP (measured in 20 hospitals)
Source of E coefficients [2]	NRPB-R262 (r/fl) NRPB-R250 (CT)	NRPB-R262 (r/fl) 'Practical CTDI'(CT)	E values taken from literature for LU and other countries	NRPB-coeffs & E values from UNSCEAR 2000 for other countries	Danish M/C code based on MCNP & GSF phantom
Results					
Total no. exams/y (incl. dentists)	5.26 million	11.5 million	564,502	No dental data	6.8 million
Total no. exams/y (excl. dentists)	3.38 million	5.1 million	397,239	11.9 million	2.8 million
Total no. exams/y/1000 pop (incl dentists)	1156	1300	1313	No dental data	1332
Total no. exams/y/1000 pop (excl dentists)	742	570	924	1160	549
Total no CT/y /1000 pop	104	40	135	116	24
Annual S (man Sv)	5009	6000	852	17.950	2411
Annual S /head (µSv)	**1100**	**680**	**1822**	**1770**	**463**
CT annual S/head (µSv)	**642 (58%)**	**220 (32%)**	**993 (55%)**	**890 (50%)**	**173 (37%)**
References	[11-13]	[14]	[15]	[16]	[14]

[1] ESD = Entrance surface dose, DAP = Dose-area product (or KAP, Kerma-area product), CTDI = CT dose index, DLP = Dose-length product (CT)

[2] Look in the bottom of the table for references, r = radiography, fl = fluoroscopy

[3] depending on the low or high hypothesis

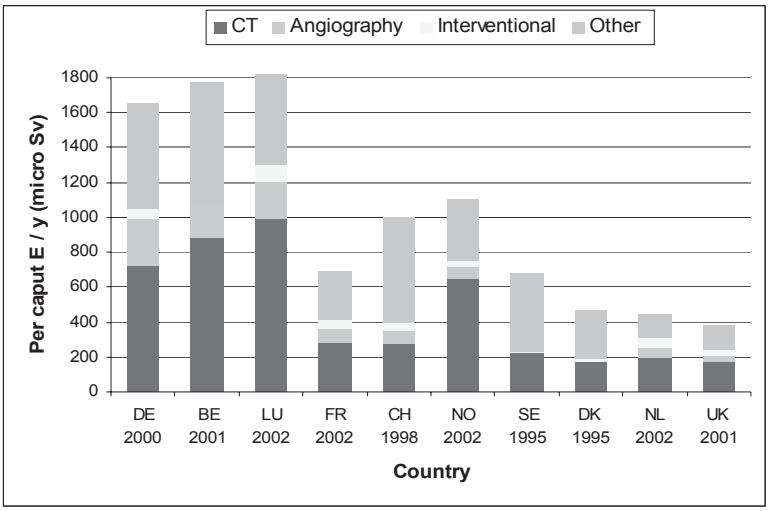
The per caput effective dose from CT, angiography, interventional and all other medical use of X-rays are shown in Figure 2.

In summary the main findings were:

- The annual frequency ranged from 483 – 1187 examinations/1000 inhabitants (excluding dental)
- The annual S ranged from 0.38 – 1.8 mSv per inhabitant
- CT's contribution to the total S ranged from 28 – 58%

The overall uncertainties in S were in the range 7 – 20% depending on survey method; thus the identified differences between countries are thought to be real.

Figure 2: Total annual per caput effective dose in ten European countries



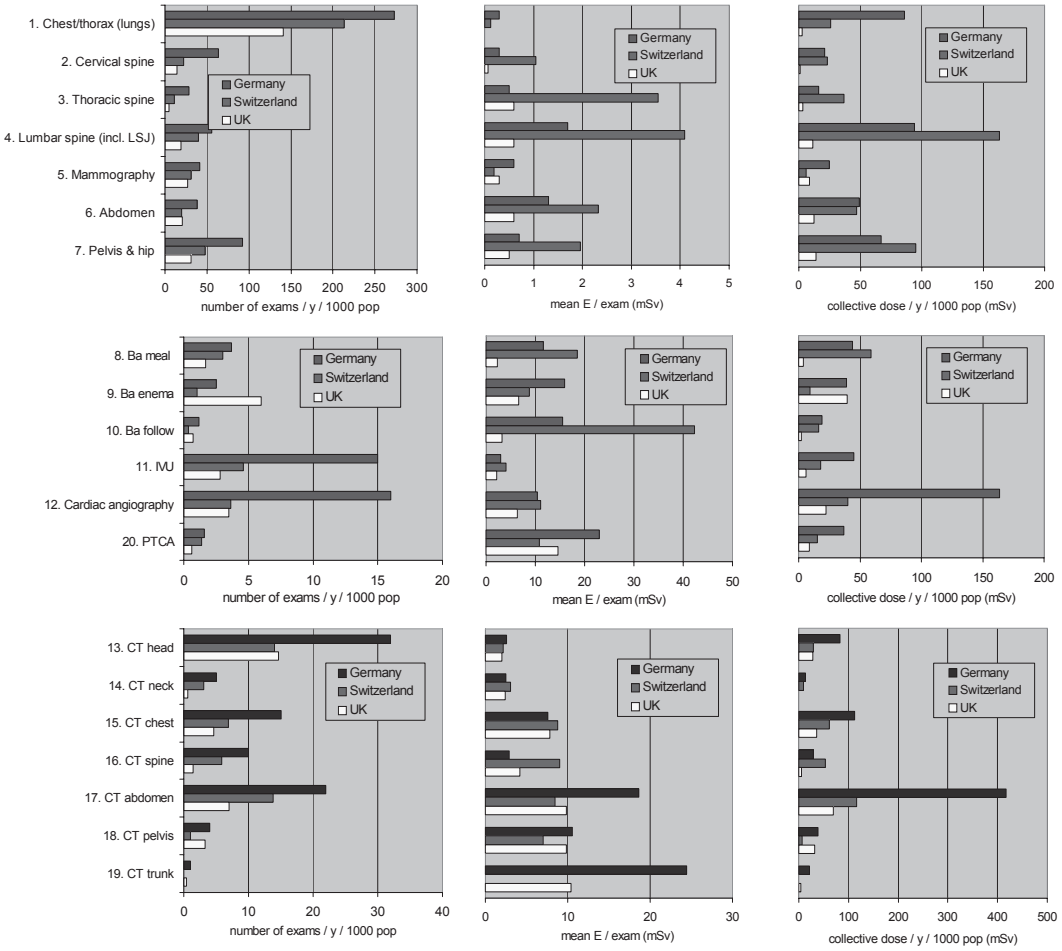
3.2 The "Top 20" examinations most contributing to the collective effective dose

The 20 types of examination or procedure that were consistently found to be amongst the highest contributors to S in all ten DOSE DATAMED countries are shown in Table 2. Frequency and dose data for these 20 types of examinations are presented from three countries in Figure 3 as an illustration.

Table 2: The twenty examination types identified to be the highest contributors to the collective effective dose in Europe

Plain film radiography (no contrast medium)	Radiography/fluoroscopy (usually with contrast)	Computed tomography	Interventional radiology
1. Chest	8. Barium meal	13. CT head	20. PTCA
2. Cervical spine	9. Barium enema	14. CT neck	
3. Thoracic spine	10. Barium follow	15. CT chest	
4. Lumbar spine	11. IVU	16. CT spine	
5. Mammography	12. Cardiac angiography	17. CT abdomen	
6. Abdomen		18. CT pelvis	
7. Pelvis and hips		19. CT entire trunk	

Figure 3: Frequency and dose data for the 'Top 20 exams' in Germany, Switzerland and the UK

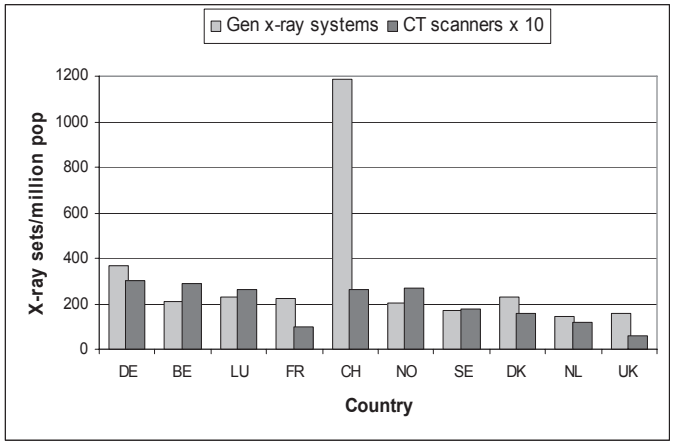


4. Discussion

The demonstrated differences between the ten European countries were discussed in elucidation of the national health care system and regulatory framework**:**

- The quantity of available X-ray equipment is shown in Figure 4. Particularly the number of CT's seems to influence the value of S in upward direction.
- The number of non-radiologist doctors involved in both the justification and performance of x-ray examinations seems to influence the value of S.
- The differences may be explained by financial incentives: In countries where the radiologists usually have a fixed salary, the frequency of X-rays is lower compared to countries where they are paid "per examination".
- The health care system also seems to influence the value of S: Countries with centralised healthcare systems may find it easier to implement recommendations on the justification and optimisation of medical exposures.

Figure 4: The amount of x-ray imaging equipment per head of population in 10 European countries



5. Conclusions

The first report from the DOSE DATAMED countries "*Review of recent national surveys of population exposures from medical X-rays in Europe*" tries to explain the national differences in S. The observed differences in the population dose from medical x-rays in Europe are thought to be real, i.e. much larger than the recognized uncertainties originating from the survey design. Furthermore, the differences were found to be primarily due to the different healthcare systems operating in each country, which resulted in considerable variations in the amount of equipment and manpower devoted to medical radiology and in the financial incentives for carrying it out. Some of the results are highlighted here for illustration; others will be submitted for publication in the open literature.

In the second report the working group provide guidance on how to do such surveys in the future. For countries with limited resources for such surveys, dose data for the "Top 20" examinations are provided, as well as guidance on frequency and dose survey design. The report "G*uidance on Estimating Population Doses from Medical Radiology"* has been approved by the Commission in its working party meeting 23/24 April 2008, and will be published as an EC Report in the 'RADIATION PROTECTION' series as a pdf file on the EC DGTREN Radiation Protection website http:/ec.europa.eu/energy/nuclear/radioprotection/publication_en.htm

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TMT Handbook: guidelines for treatment and long-term follow up of people exposed to radiation after a malevolent act

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Abstract. Public health emergencies may be triggered in diverse scenarios including malevolent use of radioactive material. The change in global security has shifted the focus of emergency preparedness from nuclear accidents towards radiological terrorism scenarios. In such emergencies, members of the general public will most likely suffer most casualties with the numbers ranging widely depending on the scenario. Radiation doses can also range from very low to substantial life-threatening doses, and possibly combined with conventional injuries. Despite considerable efforts made in this area, there are still some gaps in terms of providing user-friendly tools for effective medical and public health response to such emergencies. The World Health Organization (WHO) participates in the collaborative research project "Triage, Monitoring and Treatment (TMT) - handbook for management of the public in the event of malevolent use of radiation" under the European FP6 programme. WHO coordinates development of the chapter on hospital phase of response and long-term follow-up. The chapter addresses diagnosis, treatment and follow-up of acute radiation syndrome, local radiation injuries, internal contamination, combined injuries, as well as psychological impact management. Although this chapter is focused on actions conducted at hospital level, critical links between pre-hospital and hospital responses are also addressed. The chapter is based on best available international guidance on health interventions in radiation emergencies, current European consensus and relevant IAEA and WHO publications. A wide distribution of the TMT handbook is envisaged and its incorporation into national exercise and training programmes will be encouraged.

KEYWORDS: radiation emergency, medical and public health response, malevolent use of radioactive material .

1. Introduction

Actual or potential major health emergencies are objects of intense public attention and debate. Health crises may be triggered by sudden, catastrophic events as well as by complex continuing emergencies and slow onset disasters, in many diverse scenarios e.g. natural disasters, technological disasters and deliberate events.

In many countries, national radiation emergency response plans have long been mainly focused on nuclear accidents. More recently, the risk of malicious use of radioactive material has shifted the

focus demanding authorities being prepared also to respond to malevolent uses of ionizing radiation, including the probability of mass casualty events. The casualties will most likely be members of the public where the number of affected people can widely vary according to the scenario and radiation doses can range from very low to potentially letal, combined with conventional injuries. Radiological attacks are mainly aimed at creating disruption and panic in society. They are more likely to give rise to psychological consequences among public, and even among responders, if compared to other malicious acts.

The European Commission is sponsoring a research project under the 6th EURATOM framework called "Triage, Monitoring and Treatment - handbook for management of the public in the event of malevolent use of radiation" (TMT project). Under the TMT project several tasks were undertaken in six work packages aimed to develop guidance for triage, monitoring, treatment and follow-up.

2. Objectives of Work Package 4

The objectives of work package 4 (WP4), led by WHO, were to develop evidence-based practical guidelines on:

- Treatment, health care management and long-term health surveillance of persons affected by events involving the malevolent use of ionizing radiation including acute radiation syndrome, local radiation injuries, radiological contamination and combined injuries;
- Management of "worried well" persons not actually exposed to radiation or affected to an extent not requiring specific medical assistance;
- Prevention and management of psychological effects.

3. Working procedure

To obtain consensus on best practice, WHO convened an expert panel which brought together the expertise of professionals from the WHO/REMPAN network. The consultancy meeting on TMT WP4 was held with a dual purpose:

- to reach consensus on medical and public health issues involved in preparedness and response to radiation emergencies resulting from malevolent acts; and
- to develop as far as possible an outline of that particular chapter of the TMT Handbook.

The output of the consultancy was a meeting report that constituted the basis for the development of the draft chapter. The meeting report included:

- A summary of the discussions conducted during working sessions on diagnosis, treatment and follow-up of victims of radiation emergencies resulting from malevolent acts.
- Identified areas where consensus existed and more controversial areas requiring further research.
- Conclusions and consensus-based generic recommendations for health interventions in radiation emergencies resulting from malevolent acts.
- General recommendations on the outline of the respective chapter of the TMT Handbook.
- List of relevant terms requiring harmonization and core definitions to be further included in a glossary.
- List of relevant publications to be referenced and used for the Handbook development.

The expert panel identified some overlapping issues bridging pre-hospital and hospital responses and recommended further interaction between WHO and the consortium members involved in the TMT work package 3 (WP3), which addressed pre-hospital response. Based on that recommendation, a joint meeting WP3/WP4 was convened to ensure harmonization and consistency between the respective chapters.

To develop the chapter, a comprehensive literature review was conducted and existing European guidance for health interventions, as well as related past or current European initiatives/projects (e.g.

TIARA [1], METREPOL [2], EBMT [3] consensus) were taken into account. Relevant international documents on health interventions in radiation emergencies (e.g. IAEA/ WHO publications) were referenced.

The guidelines were developed assuming that the end users for health interventions included in the TMT Handbook may include advisory agencies with competence in emergency response, local and national health authorities, emergency responders, general practitioners, medical and paramedical emergency department staff.

4. Results

As part of the TMT Handbook (Chapter F) these guidelines are addressed to physicians, nurses and other health workers who might be responsible for actions to be taken at the first referral level (i.e. hospital response) since pre-hospital response, triage and monitoring on scene was developed under WP3. However, some critical links between pre-hospital and hospital responses are pointed out. Some assumptions about possible scenarios are made, for scaling-up the response as necessary.

The topic "public information and risk communication" is specifically addressed in another chapter of the Handbook. However, the relevance of this topic in medical and public health interventions during emergency and recovery as well as its importance for preventing/reducing psychological consequences were particularly addressed.

The guidelines are conceived for use in hospitals with basic laboratory facilities and availability of essential drugs and medicines. An individual (patient-based) approach is used for recommending clinical procedures and, where appropriate, a public health (population-based) approach is also presented.

The guidelines express an harmonized approach across the European Union and are consistent with currently existing international guidance. Actions recommended in the chapter are evidence-based statements to assist decisions about appropriate health interventions. In areas where clinical evidence is limited, recommendations were based on expert criteria according with lessons identified in recent radiation accidents.

The guidelines were structured under twelve different sections providing guidance on:

1. Notification of the incident and collection of relevant information from the field;
2. How to prepare the hospital to receive victims in radiation emergencies;
3. Arrival of victims at the hospital (transfer and admission);
4. Performing a second triage at the hospital;
5. Diagnosis and treatment of acute radiation syndrome ;
6. Management of combined injuries;
7. Diagnosis and treatment of local radiation injuries
8. Dealing with externally contaminated patients and management of radionuclide incorporation
9. Dealing with deceased victims at the hospital
10. Biodosimetry
11. Public health response
12. Prevention and management of psychological impact

Guidance on the sequence of steps to sort victims of radiation emergencies is provided, including clear instructions to deal with contaminated victims in the emergency department. It is emphasized that the triage performed at the hospital should start with a conventional triage based on clinical conditions,

[1] TIARA: Treatment Initiatives After Radiological Accidents
[2] METREPOL: Medical Treatment Protocols for radiation accident victims
[3] EBMT: European Bone Marrow Transplantation

identifying levels of priority (P1 to P3) according to the level of urgency for medical intervention. Then, the radiological triage is aimed to direct patients to the most appropriate level of medical assistance.

A simple method for primary scoring of patients with acute radiation syndrome (ARS) is proposed, based on the evaluation of severity and chronology of some medical parameters (signs and symptoms) attributable to radiation exposure: erythema, asthenia, nausea, vomiting, diarrhea, abdominal pain, headaches, temperature, blood pressure, loss of consciousness and lymphocyte count. As a result of this second radiological triage, performed at the hospital, patients may be categorized according to their individual medical needs (Table 1) . A therapeutic strategy for ARS is proposed according to the clinical status of the patient (Table 2).

Table 1: Radiological triage categories

Score	Condition
0	Bystanders who most probably were not exposed to radiation
I	Irradiated patients that can be followed on an outpatient basis or by a day care hospital structure
II	Patients needing maximum medical effort to be rescued
III	Patients predicted to develop multiple organ failure (MOF) beyond any curative perspective

Table 2: Therapeutic strategy

Score	I	II	III
Patient management	Outpatient clinical monitoring	Hospitalisation for curative treatment	Hospitalisation with prediction of MOF
Supportive care	At least daily blood cell counts for 6 days and weekly for 2 months	Supportive care, blood component therapy as necessary, symptomatic treatment of GI damage, reverse isolation	Palliative/symptomatic treatment. Blood component therapy if consider necessary
Cytokines/growth factors	No	Early administration of G-CSF for 14-21 days	Until reappraisal of score, re-evaluation during the 1st week based on laboratory and clinical symptoms revealing (or not) irreversible organ damage or MOD/MOF
Stem cell transplantation	No	Criteria to transplant: severe bone marrow aplasia persisting 14-21 days under cytokines, no residual haematopoiesis, no irreversible organ damage. Type of graft: bone marrow, peripheral stem cells, cord blood. Conditioning: fludarabine +/- antilymphocyte globulin. Don't use MTX for GVDH prevention	

G-CSF: granulocyte colony stimulating factor
GI: gastrointestinal
MOD/MOF: multiorgan dysfunction/failure
MTX: methotrexate
GVHD: graft vs. host disease

The guidelines propose a comprehensive organ specific grading to be applied beyond the first 48h. This grading method is based on a semiquantitative categorization of patients (METREPOL) which rates the severity of signs and symptoms considering four critical organ systems: neurovascular, haematopoietic, cutaneous and gastrointestinal. The integration of elements of the four organ systems determines the response category (RC), which reflects the damage to critical organs. Based on the RC the patient may be discharged, admitted to a routine care medical/surgical floor, admitted to an intensive care unit or referred to other specialized hospital.

The guidelines emphasizing that, since radiation does not cause immediate life-threatening risks, serious conventional combined injuries (e.g. burns, wounds, trauma) will take priority over concerns about irradiation and contamination. Instructions regarding surgical procedures, transfer of patients, treatment of thermal burns, stabilization of fractures and management of contaminated wounds are included.

The clinical evolution of local radiation injuries[4] (LRI) is described. Guidance on how to identify a skin lesion attributable to radiation exposure is provided. Main diagnostic tools are proposed and different therapeutic options are presented, including the novel approach of regenerative medicine combining dosimetry-guided surgery with autologous mesenchymal stem cell therapy. The guidelines emphasize that the treatment of severe LRI should be performed at specialized institutions.

Practical guidance for general management of contaminated patients is associated with procedures for external decontamination using specific or non-specific washing solutions. Decontamination of normal skin, wounds and natural orifices is considered, with objective criteria for deciding when to stop external decontamination efforts.

Principles of treating internal contamination are based on the criteria adopted by TIARA, in terms of committed effective dose assessed by bioassay. The guidelines point out that the clinical evidence about use of decorporating and blocking agents is limited. Detailed explanation is provided about the few agents that have been proven to be effective (e.g. potassium iodide, DTPA, Prussian blue) and additional information about other possible agents is provided in an annex.

Blood sampling procedures for cytogenetic dosimetry are described, and recommendations about packaging and transport of blood samples are also provided.

The section on public health response addresses the role of the health authorities during the emergency and provides guidance for scaling-up the response as the magnitude of the event unfolds. In emergencies with many victims it is particularly important to put into place a scheme to bring people into the health care system yet avoiding overwhelming the hospitals. This section includes instructions on how to establish and manage peripheral health care centres during radiation emergencies. Guidance on how to deal with an outbreak of an unusual disease attributable to radiation exposure is also provided.

Criteria for long-term follow-up are presented in a dual approach:

1. individuals who developed deterministic effects (e.g. ARS, LRI);
2. population exposed to low radiation doses.

Guidance for prevention and management of the psychological impact is presented in an explanatory rather than prescriptive text, including:

- How to deal with "worried well" people;

[4] Cutaneous radiation syndrome (CRS) is also proposed to describe the inflammatory skin reaction associated with a particular cytokine profile observed after radiation exposure. However, following exposure to high doses of IR it is not only the skin which is involved, but also the subcutaneous tissue and even muscles and bones and for the purpose of the handbook this entity is termed as LRI.

- How to identify people at higher risk of developing mental health problems (e.g. children, pregnant women, mothers with young children);
- How to deal with acute stress reactions;
- How to prevent, predict and treat post traumatic stress disorder

6. Current status and next steps

The draft TMT Handbook was distributed to a wide range of end-users (radiation emergency response organizations in the European Union and associated states), who were invited to evaluate and, if possible, to test the handbook in their national emergency response exercises. Comments on the draft handbook and possible experience from its use in exercises will be presented by end-users during a Feedback Workshop. A final version of the handbook will be produced after a peer-review process.

A training course based on the TMT Handbook is scheduled for the first quarter of 2009. This course aims to strengthening of national capability for response to malevolent acts involving a use of radiation. The training will also offer an opportunity to identify common challenges and ways of better harmonization of response strategies. In addition, the participants will be encouraged and expected to promote the incorporation of the TMT Handbook into exercises and training programmes in their own countries and disseminate it widely among national and local emergency response institutions.

7. Acknowledgements

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Dosimetric characterization of a brachytherapy applicator using MCNP5 modelisation and in-phantom measurements.

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Abstract. Brachytherapy is a radiotherapy treatment where encapsulated radioactive sources are introduced permanently (interstitial seeds) or temporally (interstitial or intracavitary devices) within a patient. When high dose rate sources (HDR) are used in intracavitary treatments, high doses can be locally imparted within the patient body. Monte Carlo simulation codes are powerful tools to simulate sources and devices to help physicists in treatment planning as well as to evaluate the dose received by the patient. In multiple types of gynaecological cancer, intracavitary brachytherapy can be used combined with other therapy treatment to give an additional local dose to the tumour. In these cases, different types of applicators can be used in order to increase the dose imparted to the tumour while the effect on healthy tissues is restricted. Due to the proximity of some more radiosensitive organs (i.e. rectum), the dose distribution into the tissue near the applicator has to be known as precisely as possible in order to avoid damage to these organs. The aim of this work is to model both applicator and source in order to evaluate the dose at a reference point as well as the effect of the materials constituting the applicators on the near field dose. The MCNP5 code based on the Monte Carlo method has been used for the simulation. A gynaecological applicator, consisting of a metallic intra-uterine tube with a plastic vaginal applicator, and a Microselectron HDR Ir-192 source have been simulated to evaluate the dose distribution. A solid phantom (PMMA) has been designed to perform measurements around the applicator with radiochromic films (type Gafchromic EBT). The isodose curves obtained are compared with curves calculated with the F4MESH tally of MCNP5.

KEYWORDS: brachytherapy, Monte Carlo method, MCNP5, dosimetry, radiochromic films, pinpoint chamber

1. Introduction

Brachytherapy consists in using an encapsulated source at short distance from the target volume for irradiation of malignant tumour or non-malignant lesions. It can be used alone or in combination with an external radiotherapy treatment. Compared to external beam treatment, the physical advantages of brachytherapy result in a better localization of the dose into the tumour and better protection of healthy tissues. In the case of intracavitary afterloaded high dose rate treatment (HDR), a source of high activity is temporary introduced into the patient body. Depending on the tumour localization, different applicators devices can be used to achieve a right positioning of the source. Due to the high dose rate, dose distribution has to be known with a good precision to perform the treatment planning. It has to be evaluated in the near field to ensure that the tumour receive the prescribed dose but also at larger distances to evaluate the dose imparted to organs with higher risk like bladder or rectum for a gynaecological treatment. In the AAPM TG 56 [1], quality assurance advices are given to ensure the good quality of the treatment and the security of the patient. These requirements are focused on the control of the irradiation time, the source localisation and the dose distribution around the applicator device. To meet the quality requirements for dose evaluation, both measurements and Monte Carlo

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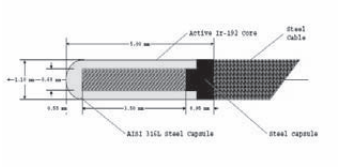
calculations can be used. In the present work, the case of HDR treatment and gynaecological applicator (consisting of an intra-uterine tube and vaginal cylinders) has been investigated

2. Instrumentation and method

2.1 Modelling of the source and applicator

The source considered in this work is an HDR Ir-192 Microselectron of Nucletron. A model of the source including its capsule (316L stainless steel) and guiding cable (304 stainless steel) has been developed. The energy spectrum was obtained from the JANIS database [2]. A layout of the source model can be seen in figure 1.

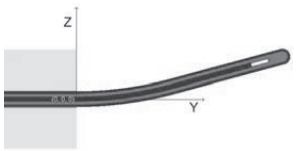
Figure 1: source model



In the case of a gynaecological treatment, an applicator is used for both the right positioning of the HDR source and the protection of healthy tissues. The applicator used in this work consists of two parts: an intra-uterine tube and a vaginal applicator. The intra-uterine part consists of a metallic tube (AISI 304, density of 7.92 g/cm³) with a 15° inclination of the end side. The vaginal applicator is formed by two plastic cylinders (PPSU, density of 1.29 g/cm³) of 2 cm diameter and 2.5 cm length. The model developed for MCNP5 calculation is shown on figure 2. The figure 3 represents an axial view of the source into the applicator tube.

Figure 2: applicator model

Figure 3: source into applicator



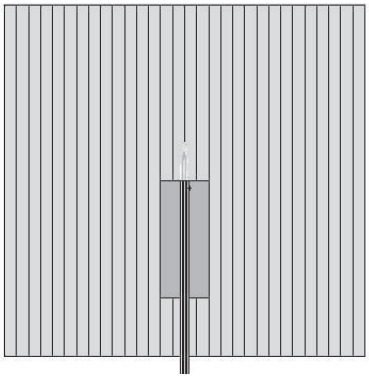
2.2 MCNP5 Calculation

The simulations have been performed using the MCNP5 code [3] based on the Monte Carlo method. Two types of calculation have been done for the dosimetric study of the irradiation device (source and applicator). For dose evaluations, the *F8 tally (photon and electron), which gives energy value deposit in a cell (in MeV) has been used. For obtaining isodoses around applicator device, a F4MESH calculation, using DE and DF cards to transform fluence (particle/cm³-s) into dose (Gy), has been performed. Values for these cards have been obtained using the energy mass absorption coefficient provided by NIST [4]. The ENDF/B-VI cross section library has been used. The voxel size for calculation depends on the size of the measuring device used in the comparison between calculation and measurement. Only photon calculation has been done. The cutoff has been fixed to 1 keV for photons and 20 keV for electrons. In each case, 500 millions of particles have been launched to improve statistics [3].

2.3 Design of the PMMA phantom

To allow the good positioning of both measuring device and gynaecological applicator, a PMMA phantom has been developed. It consists of 30 PMMA sheets (density 1.19 g/cm³) of 15*15*0.5 cm. The four central sheets have been manufactured in order to contain the applicator. Other sheets allow the positioning of different measurement device, like radiochromic films or a small ionization chamber. To allow comparison between in-phantom measurements and MCNP5 calculations, a model of the phantom has been developed. The layout can be seen on figure 4.

Figure 4: MCNP5 model of the PMMA phantom



2.4 Dose measurement devices

Different devices have been used to perform the real measurements in the phantom.

2.4.1 Radiochromic films

Radiochromic films are self developing films consisting of a layer of Pentacosa-10,12-diynoic acid (37 µm) between two layers of clear polyester (97 µm each). They are widely used for the evaluation of relative doses but also for absolute absorbed doses because of being tissue equivalent (Z_{eff}= 6.90) and showing a high spatial resolution. In this study, Gafchromic EBT© have been used to measure isodoses. Each film used has been scanned with a VIDAR VXR12 medical scanner to assess the uniformity of the reading (optical density, OD) before use. The dose calibration has been performed for 18 different doses ranging from 0 to 6.8 Gy delivered by a 6 MV photon beam provided by a LINAC medical accelerator. The reading has been realized 12 h after irradiation using a VIDAR VXR 12 and the software RITT113 [6]. The spatial resolution of the reading is 85 µm per pixel.

2.4.2 Pinpoint ionization chamber

In order to measure a point dose, a small open air ionization chamber CC04 of Wellhöfer (active volume of 0.04 cm³, 3.6 mm length) has been used to evaluate the dose at some reference points, and at different distances from the source axis. The chamber has been calibrated for the energies of the ^{60}Co and a correction factor has been used for the ^{192}Ir. It has been inserted into the PMMA phantom sheets.

3. Discussion and results

3.1 Comparison of gafchromic measurements and MCNP5 calculation

For the in-phantom measurement, the gafchromic film (15 cm*12,5cm) has been inserted between two PMMA sheets at 1 cm from the intra-uterine tube axis. The total dose is the sum of those delivered at four different positions of the source into the intra-uterine tube in order to minimize the dependence of

the source position. After scanning with the VXR 12 and applying calibration (OD= function of dose), a dose matrix has been obtained. Isodose curves can be drawn using the RITT 113 software. These measured curves have been compared with those ones obtained using F4MESH tally of MCNP5. For this calculation, the voxel size has been fixed at 1*1*0.037 mm where 37 µm corresponds to the thickness of the active layer in the Gafchromic film. Dose profiles can also be obtained. The figure 5 show the comparison of measured and calculated isodose curves. A maximum shift of 1 mm can be observed. The figure 6 shows a vertical profile of both measured and calculated doses taken in the center of the isodose curves. Both profiles are in good agreement. In general, the maximum difference between both dose matrices did not exceed 4%.

Figure 5: Comparison between calculated and measured isodose curves

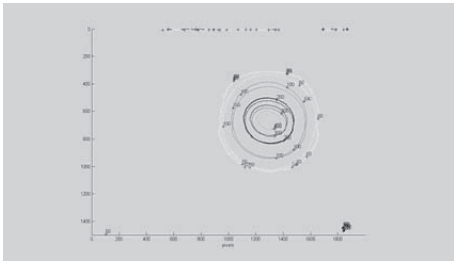
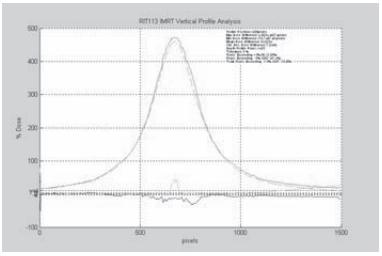


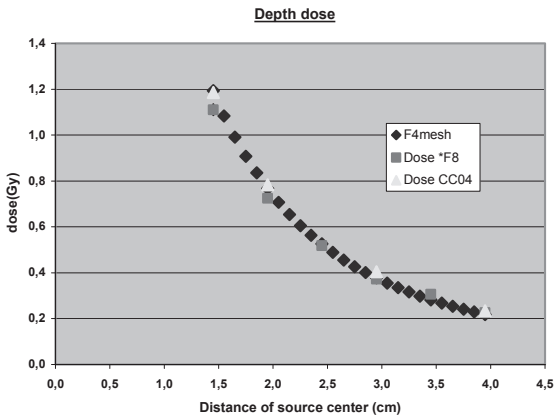
Figure 6 : Comparison between calculated and measured vertical dose profiles



3.2 Comparison between pinpoint dose measurement and MCNP5 calculation

The Wellhöfer CC04 chamber has been inserted into the PMMA phantom at different distances of the intra-uterine tube axe (from 1.5 cm to 4 cm, with a 0.5 cm step). Total dose measurement has been obtained with 4 positions of the source like explained in 3.1. Dose was calculated using calibration factor (provided by manufacturer, in water and for ^{60}Co $N_{D,W}$ =9.48 10^8Gy/C) and correction factors for atmospheric pressure, temperature, isotope and materiel (PMMA). The absorbed dose was compared with two different MCNP5 calculations: a *F8 energy deposition tally in the active cavity of the chamber and an F4MESH (corrected with DE, DF cards calculated for the phantom material, see 3.1) calculation in a plane perpendicular to the intra-uterine tube axis that also contains the axis of the cylindrical CC04 chamber. Measurements and calculations have been made for distance ranging from 1.5 cm to 4 cm from the axis of the source. Results of both calculations and measurements are presented in figure 7.

Figure 7: Comparison between measured and calculated depth dose with pinpoint



Calculated and measured results show a general good agreement. The matching seems to be better with the F4MESH calculations mostly at smaller distances; we can see differences between 0.6% for the 1.5 cm distance and 6% for 4 cm distance. Instead, comparing measurement with *F8 energy deposit tally lead to a slightly higher difference ranging from 7 % at 1.5 cm distance to 5% at 4 cm.

4. Conclusions

The PMMA sheet phantom allows a good duplication when necessary of dose measurement devices, which is of great importance to compare calculations and measurements.
Both calculated and measured isodose curves show a good agreement and also for absorbed doses. This allows us to use the MCNP5 model for dose calculations at points that are not accessible for physical measurements like on the intra-uterine tube surface.
In the future, results (measurements and calculation) will be compared with commercial treatment planning systems.

Acknowledgements

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Testing and intercomparison of model predictions of radionuclide migration from a hypothetical area source

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Abstract. This work was carried out as part of the International Atomic Energy Agency's EMRAS program. One aim of the work was to develop scenarios for testing computer models designed for simulating radionuclide migration in the environment, and to use these scenarios for testing the models and comparing predictions from different models. This paper presents the results of the development and testing of a hypothetical area source of NORM waste/residue using two complex computer models and one screening model. There are significant differences in the methods used to model groundwater flow between the complex models. The hypothetical source was used because of its relative simplicity and because of difficulties encountered in finding comprehensive, well-validated data sets for real sites. The source consisted of a simple repository of uniform thickness, with 1 Bq g^{-1} of uranium-238 (^{238}U) (in secular equilibrium with its decay products) distributed uniformly throughout the waste. This

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approximates real situations, such as engineered repositories, waste rock piles, tailings piles and landfills. Specification of the site also included the physical layout, vertical stratigraphic details, soil type for each layer of material, precipitation and runoff details, groundwater flow parameters, and meteorological data. Calculations were carried out with and without a cover layer of clean soil above the waste, for people working and living at different locations relative to the waste. The predictions of the two complex models showed several differences which need more detailed examination. The scenario is available for testing by other modellers. It can also be used as a planning tool for remediation work or for repository design, by changing the scenario parameters and running the models for a range of different inputs. Further development will include applying models to real scenarios and integrating environmental impact assessment methods with the safety assessment tools currently being developed by the IAEA.

KEYWORDS: NORM, area source, scenario development, model testing, model intercomparison

1. Introduction

The Environmental Modelling for radiation Safety (EMRAS) project was set up by the IAEA in 2003 to continue and expand upon the work carried out in earlier programs such as BIOMOVS, BIOMASS and VAMP. A working group on materials containing naturally occurring radionuclides (NORM) was set up to look at modelling of the movement of naturally occurring radionuclides in the environment. The aims of this group included looking at legacy sites, existing sites, and planning for future operations, with particular emphasis on the assessment or prediction of health and environmental impacts of NORM. These materials can include waste, residues, and products, with a very wide range of volumes and radionuclide concentrations. The large number of naturally occurring radionuclides and the wide range of chemical and physical properties of these radionuclides have to be taken into account in the models.

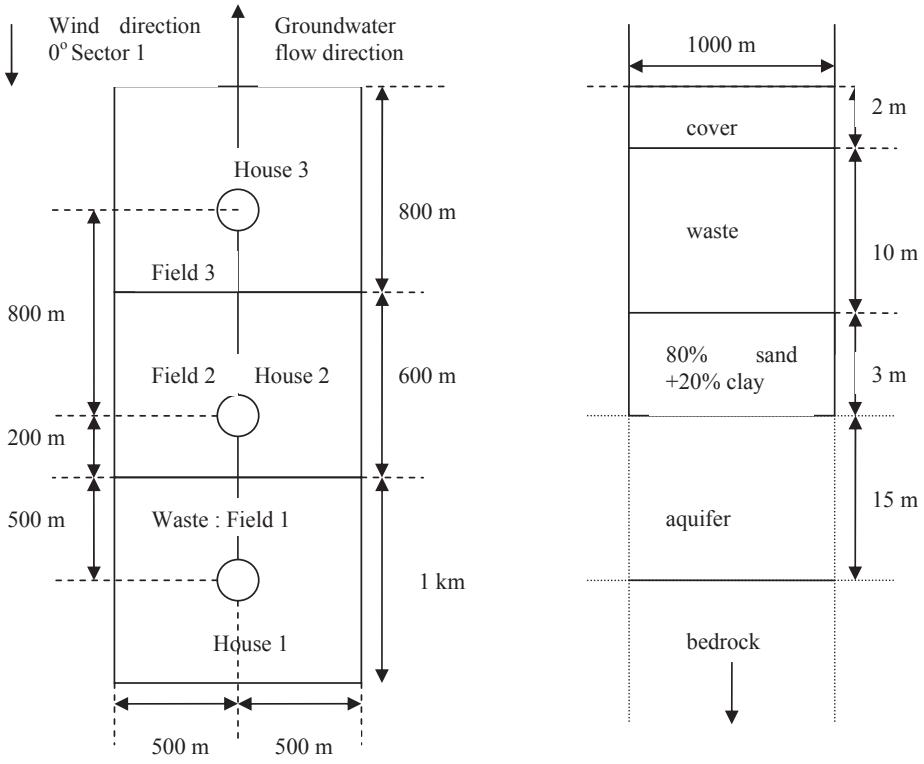
Further aims of the work were to evaluate existing models, develop scenarios for testing and verifying models, and develop new models. Very few models, and no well-documented scenarios for model testing, were available at the start of the program. Therefore a suite of hypothetical scenarios (a point source, an area source, and an area source plus river) was developed for validating and comparing models. This work describes the use of the hypothetical area source scenario for model testing and presents some of the results of the testing and model intercomparisons.

Potential applications of this work include the evaluation of legacy sites, assessment of remediation strategies for legacy sites and existing operations, and prediction of potential impacts of future operations (in particular, assessment of different management strategies).

2. The area source scenario

The main physical features of the site are shown in Figure 1. A detailed description of the scenario, including the modelling input data, can be found in [1]. The radionuclides are assumed to be uniformly distributed throughout the waste. Modellers were also asked to calculate doses to people working in each of the three fields and living in the house within that field. The modellers were asked to carry out the calculations for both covered and uncovered waste, and to consider the effect of rotating the wind rose through all four quadrants.

Figure 1: a plan (left) and vertical profile (right) of the hypothetical site (not to scale)



3. Models used in this work

The models used were PRESTO-CPG ver.4.2, RESRAD-OFFSITE, and DOSDIM + HYDRUS.

PRESTO (Prediction of Radiological Effects Due to Shallow Trench Operations) [2] is a computer package for the maximum annual effective dose to a critical population group from contaminated soil layers, for scenarios involving near surface waste disposal, soil cleanup, agricultural land application, and land reclamation. The package is designed to calculate the maximum annual effective dose to a critical population group for a range of scenarios, and includes models which simulate the transport of radionuclides in air, surface water, and groundwater pathways, and evaluate exposures through ingestion, inhalation, immersion and external exposure pathways. Although the package is designed for screening calculations, the models used for groundwater dynamics (infiltration, leaching, flow and extraction) are sufficiently detailed to avoid unnecessarily conservative results. The radionuclide migration model assumes the same partition coefficient (K_d) values for parent and daughter radionuclides in decay chains. The model also assumes that the waste is separated from the aquifer by one unsaturated soil layer. Simulation time is limited to 10,000 years.

RESRAD-OFFSITE [3-4] is designed to handle the assessment of both on-site and off-site impacts for situations such as buried waste and landfill (uncovered waste). The package allows for an optional cover layer, up to five partially saturated layers below the waste, and an aquifer (saturated layer). Allowance is also made for the effects of surface water bodies such as ponds, lakes and rivers, and for variations in land use near the disposal site. The models used in the package are complex and require considerable input data, but provide considerable

flexibility when carrying out assessments. The package has been designed to be user friendly and is well documented. The user can select a range of exposure pathways appropriate to the scenario being considered. The ability to carry out both deterministic and probabilistic is also provided. Only deterministic calculations were used for the work described here.

Radionuclides are removed from the waste by leaching, surface runoff, erosion, resuspension (dust) and exhalation (radon). A Gaussian Plume model is used to calculate airborne radionuclide activity concentrations at downwind locations and allows for both wet and dry deposition. The groundwater transport model is also a Gaussian dispersion model, which takes both horizontal and vertical dispersion into account when calculating radionuclide concentrations at off-site locations. This model also considers the decay of the parent radionuclide, the ingrowth of progeny radionuclide(s), and their respective retardation due to sorption/desorption in the solid phase. Drinking water is drawn from a well and the effects of irrigation using water from the well or a surface water body can be estimated using a food chain model.

DOSDIM (+ HYDRUS) calculations involved the use of two modelling packages. DOSDIM (DOSe DIstribution Model) is a compartmental type of model of the biosphere, partly dynamic, depending on the time frame and on the exposure pathways considered. It includes a module, based on a multi-source Gaussian dispersion model, which calculates radon concentrations in the air from point and area sources [5]. The DOSDIM package has been used in the BIOMOVS [6], VAMP [7-8] and BIOMASS [9] model validation and verification studies.

The radon dispersion was calculated by subdividing the area of the repository (1 km x 1 km) into of 100m × 100m cells. At the point of interest (e.g. house 2 in Figure 1), the contribution from each cell was calculated, and the individual contributions were then summed to give the total radon concentration [1]. For the covered waste scenario a radon exhalation rate of 0.02 Bq m^{-2} s^{-1} was used, while a value of 1 Bq m^{-2} s^{-1} was used for the uncovered waste scenario. For the uncovered waste situation the exhalation of radon from the waste directly into the house was included. The effects of erosion on the thickness of the cover were also allowed for in the calculations.

HYDRUS 1D and HYDRUS 2D were used for modelling the transport of the radionuclides in the variably saturated medium under the waste. Both models use finite element methods to simulate water and solute movement in unsaturated, partially saturated, or fully saturated porous media. For this work the one-dimensional version HYDRUS 1D was used to model the transport of the radionuclides through the vadose (unsaturated) zone under the waste into the aquifer (saturated zone). The concentrations of the radionuclides in the aquifer at the location of the exposure point (a well at the house) were then calculated with HYDRUS 2D using the output values from HYDRUS 1D as input.

4. Results

A number of exposure pathways were considered, including external exposure, inhalation of radon and contaminated dust, and ingestion of contaminated water and food. The effects of erosion on covering material were also considered, and the RESRAD-OFFSITE package gave the modellers the option of considering the effects of different types of land use following the deposition of the waste material.

The important factors which can influence the impact of surface and near-surface disposal of waste include future land use, the diet and general life-style of the inhabitants of the area, rainfall, groundwater transport, surface water transport, radon exhalation, the presence or absence of covering material above the waste, and erosion. The models should be able to simulate each of these processes.

Future land use can both influence and depend on the outcome of an assessment of the potential impact of a proposed waste repository, and can also affect doses once the waste is emplaced.

There are a large number of exposure pathways to be considered for scenarios of the type discussed here. However, in general, the exposure pathways can be put into groups; these groups are external exposure, exposure to airborne radionuclides (dust, radon, and thoron), food chain pathways, surface water transport pathways and groundwater transport pathways.

The effects of surface water transport were not considered in this scenario. Covering the waste should significantly reduce the contributions of airborne radionuclides, and external exposure, provided the cover remains intact. However, for long-term predictions the effect of erosion can be expected to be important. Erosion of the cover should increase the dose contributions from the airborne radionuclides and from external exposure, while erosion of the waste material itself should decrease the contributions from all exposure pathways. In addition, because groundwater transport is much slower than airborne transport, there should be significant delays in the effects of the groundwater pathways relative to the placement of the waste and the removal of the cover and waste by erosion. These considerations helped to guide the modellers in both developing the models used in this study, and in interpreting the results of the scenario testing.

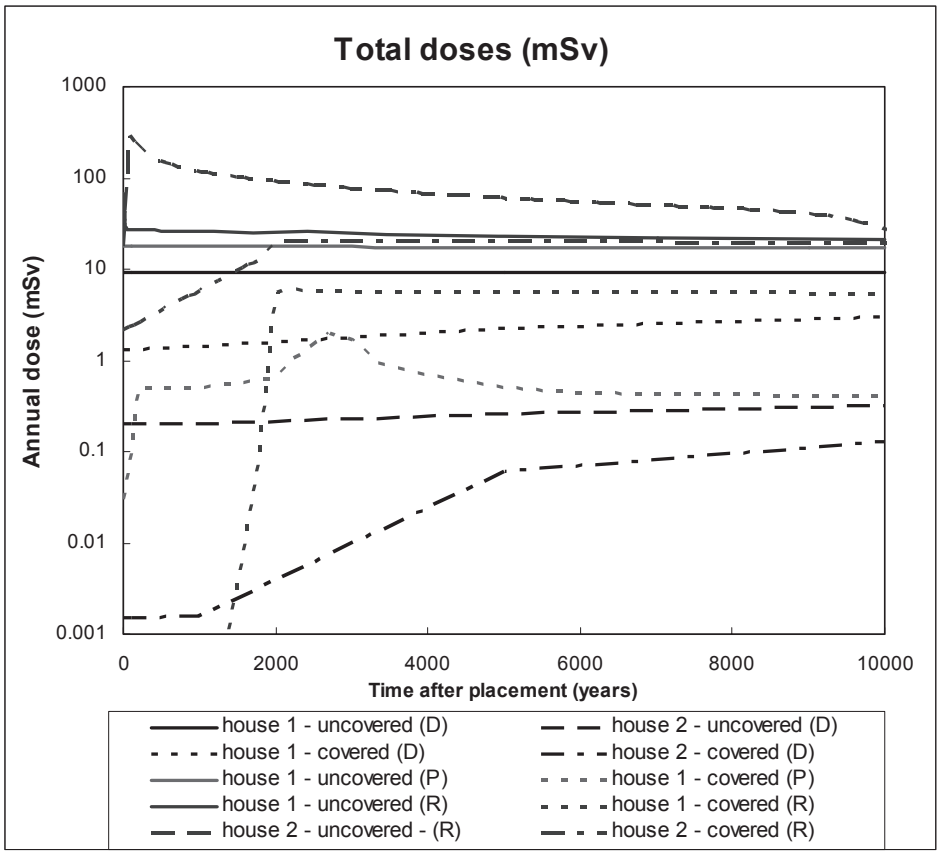
The detailed results are presented in the main report [1] of the NORM working group (to be published). Some of these results are presented in the following sections. Total dose predictions are discussed in Section 4.1, dose contributions from individual exposure pathways are discussed in Section 4.2, and ^{238}U concentrations in well water are discussed in Section 4.3.

Most of the results presented in the following sections were generated by the RESRAD-OFFSITE and DOSDIM (+HYDRUS) models.

4.1 Total doses

Total doses were calculated in all models by summing the contributions from all exposure pathways included in the model. The results for house 1 and house 2 are shown in Figure 2.

Figure 2: Total doses for houses 1 and 2, as calculated by the models PRESTO, DOSDIM and RESRAD-OFFSITE.



In Figure 2 the labels (D), (P) and (R) refer to the models DOSDIM (+ HYDRUS), PRESTO and RESRAD-OFFSITE respectively. DOSIM results are presented as black lines, while PRESTO results are represented by red lines and RESRAD-OFFSITE results are represented by blue lines. This allows comparison of the prediction of different models by comparing curves of the same line type but with different colours. The solid lines refer to the doses for a resident of house 1 for uncovered waste. The dashed lines (– – –) refer to house 2 for uncovered waste. The dotted lines (·····) refer to house 1 for covered waste. The broken dashed lines (– - – -–) refer to house 2 for covered waste.

Figure 2 shows a number of interesting features. In general, the RESRAD-OFFSITE predictions are higher than those from PRESTO and DOSIM (+HYDRUS). In particular, the RESRAD-OFFSITE results appear to be a factor of approximately 100 higher than the DOSDIM (+ HYDRUS) results. The ratio between the waste with no cover case and the waste with cover case is approximately the same for times greater than 5,000 years, but is greater for RESRAD-OFFSITE than for DOSDIM(+ HYDRUS) for times less than 5,000 years. The reason(s) for these differences are not understood at this time.

In RESRAD-OFFSITE the erosion rate was calculated from the rainfall, infiltration and run-off data. For this scenario the erosion rate was estimated as 0.99 millimetres per year

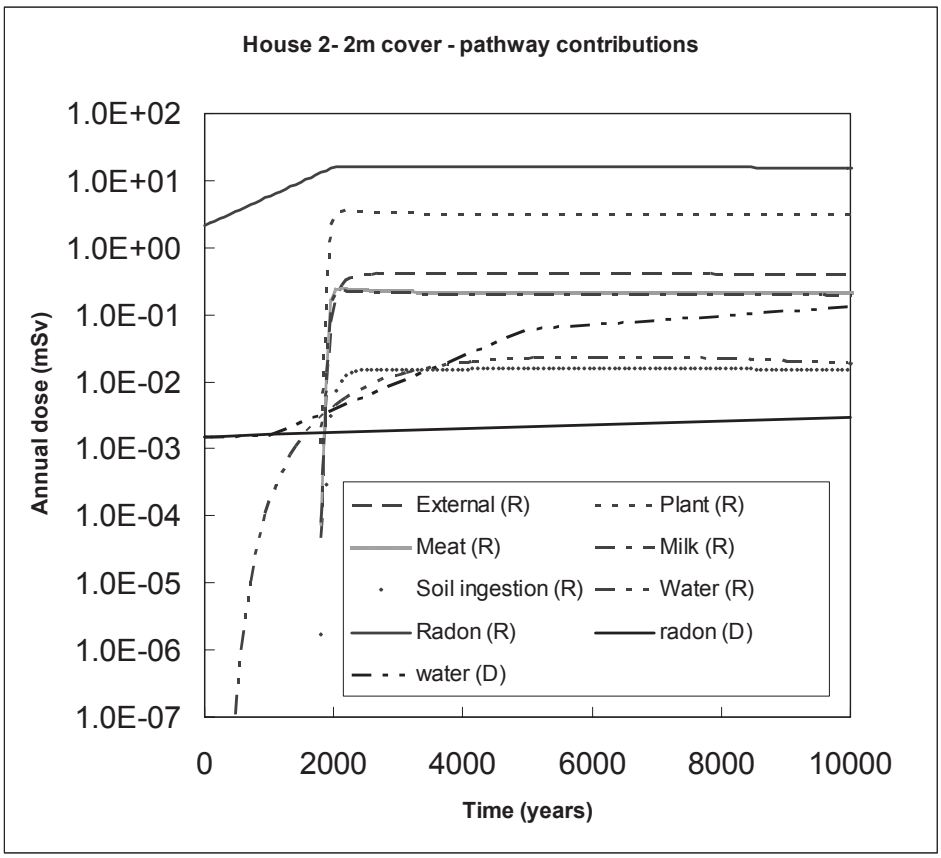
(approximately 1 metre per 1,000 years). The erosion of the cover could explain the increase in dose over the first 2,000 years for the covered waste.

To examine the reasons for the reasons for this increase in dose, it is necessary to look at the contributions to the total dose from individual pathways.

4.2 Dose contributions from individual pathways

The predicted dose contributions for the important exposure pathways are presented in Figure 3.

Figure 3: Dose contribution from individual pathways, calculated by RESRAD-OFFSITE



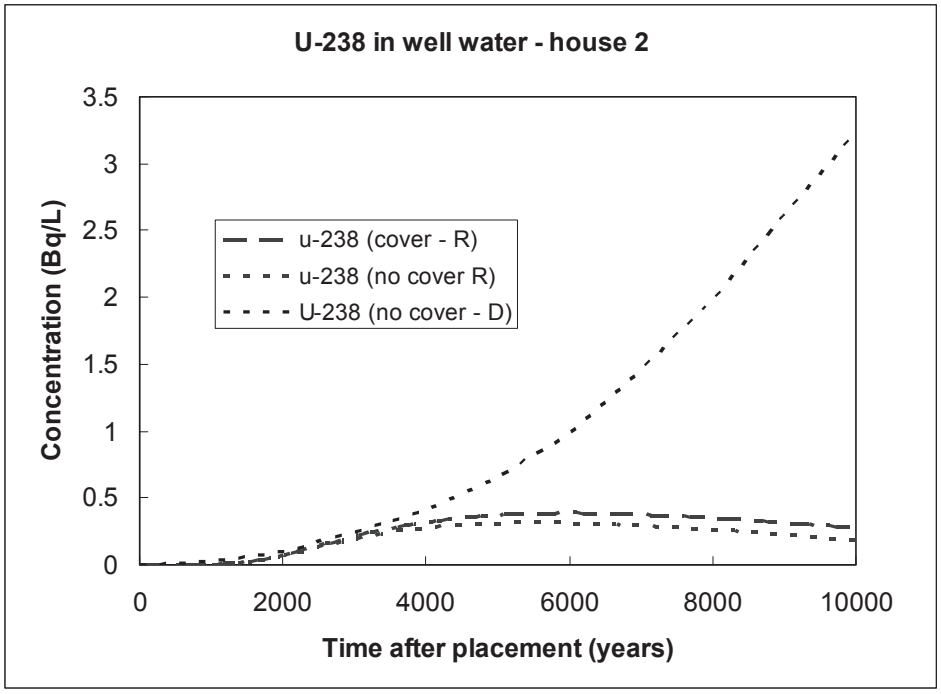
In Figure 3 there are several points to note. RESRAD-OFFSITE predicts significantly higher radon doses than DOSDIM (+ HYDRUS). The reason for this difference is not understood at this time. Leaving aside the possibility of mistakes by the modellers, there are several factors that can influence indoor and outdoor radon concentrations. Outdoor radon concentrations are strongly influenced by atmospheric conditions, and radon concentrations inside a dwelling tend to be dominated by the building materials used in constructing the dwelling, the ventilation rate, the rate at which radon enters the dwelling as a result of exhalation from the soil under the dwelling, and the presence or absence of a basement. Clearly, further work is needed to explain the differences in the model predictions.

Figure 3 indicates that the increase in total dose predicted by RESRAD-OFFSITE during the first 2,000 years is due to the increased exhalation of radon as the cover is removed by erosion. This behaviour is not reproduced by the other two models.

4.3 Dose contributions from individual radionuclides

Another useful comparison of model predictions was achieved by examining the predicted radionuclide concentrations in well water. The results of these calculations for RESRAD-OFFSITE and DOSDIM (+ HYDRUS) are shown in Figure 4.

Figure 4: ^{238}U concentrations in well water for house 2.



DOSDIM (+HYDRUS) predicted the same concentrations for both the uncovered and covered waste cases. Both models predicted that the ^{238}U will start to appear in the well water after approximately 1,000 years. However, beyond that point the model predictions differed markedly.

If there were no erosion the ^{238}U concentration in well water should be expected to increase with time until most of the ^{238}U has been leached from the waste. However, erosion should remove the waste and hence reduce the source term. Therefore the ^{238}U concentration should increase at first but then start to decrease as the effects of erosion reduce the total amount of ^{238}U (in the waste) available for leaching into the groundwater. The effect of cover material would be expected to delay the expected decrease in ^{238}U concentration in well water because of the extra time needed to erode the cover. The RESRAD-OFFSITE predictions are consistent with this.

5. Conclusions

There appear to be significant differences between the predictions of the three models tested in this study. The fact that the PRESTO predictions are lower than the RESRAD-OFFSITE

predictions is interesting because PRESTO is designed to be used for screening calculations, and should be more conservative that RESRAD-OFFSITE

There are many processes which can affect the health and environmental impacts of surface and near-surface disposal of waste. These include erosion (of both cover material and the waste itself), leaching, ground water transport processes, radon exhalation, rainfall, meteorology, future land use, and the use of (possibly) contaminated water for irrigation and domestic use. These processes are complex, which means that the development of models for simulating the transport of radionuclides in the environment for this type of scenario is not a simple matter. In addition, because of the complexity of the models and the large amount of input data needed by the models, there are many choices to be made by the user when setting up computer packages to model this type of scenario. This was noted by the DOSDIM user, who pointed out several important omissions in the original scenario specifications, and by the RESRAD users, who had difficulty agreeing on the land use specifications for the calculations. The resolution of these difficulties led to several important conclusions:

1. it is not always possible to specify the scenario without going through an iterative process of testing and modification;

2. good communication between modellers is essential, to ensure that all modellers use the same site specifications and the same values for environmental parameters, and produce results that can be directly compared.

3. there appear to be some significant differences between the predictions of different models.

It is unreasonable to expect that screening models and complex models will produce similar results, as these different models are designed for different purposes. This type of difference was observed in this study. However, there appear to be significant differences between the predictions of the two complex models, DOSDIM (+ HYDRUS) and RESRAD-OFFSIE, particularly with respect to the contribution from radon inhalation to the total doses predicted by the models, and the effect of cover above the waste. More work is needed to explain and resolve these differences.

A program to follow-up the EMRAS work has been suggested. Clearly, with respect to NORM there are several issues that still need to be addressed. These include the development of more real scenarios for model testing, further development and testing of the models which are currently available, and the development and testing of models to look at scenarios (such as tailings dams and lakes) which were not looked at in the EMRAS program

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The clean-up of an industrial site contaminated with slag from a former FeNb-production

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Abstract

A gamma aerial survey, performed some years ago of the territory of Belgium, did detect in the north-west part of the country an unknown site with slightly increased thorium activity.

An on the site control did reveal the presence of residues from an old FeNb-production, buried in a currently non in use field of some 4 ha. The dose-rate at 1m above ground level did vary from normal background values up to 20 times higher values. Spectroscopic analysis of samples taken at the spots with the highest dose-rate values did result in the characterisation of the radioactivity content of the slag material: 50 Bq/g for Th-232 and 5 Bq/g for Ra-226 and K-40.

Control measurements performed on nearby lying heaps of mixed material, excavated some 3 years ago from a by an asphalt layer covered area, adjacent to the contaminated field of 4 ha, did reveal the presence of similar slag underneath that area.

Detailed investigations on some 2 ton of the total amount of about 5000 ton heap material, lead to the conclusion that some 1% of the total mass is contaminated. The fraction with a median diameter of < 25 mm, representing some 46% of the total mass, didn't show a measurably increased radiation level. This was confirmed by the gamma spectroscopic analysis of some 20 samples taken from the fraction < 25 mm.

During the investigations appropriate protective measures were taken to avoid internal exposure. The gamma exposure was monitored for all personnel and resulted to be of the order of 1 μSv per working day on average.

Several control systems on radioactivity are currently being tested upon their sensitivity for the separation of the contaminated material out of the different sieved fractions. The work is planned to be accomplished by the end of April 2008.

By that time, the final destination for these NORM-residues will have to be defined.

For Those Unable to Use the Model Template, the Following Layout Should Be Followed

Page size	A4 (21 cm x 29.7 cm) - vertical (portrait) orientation
Margins	Top: 2 cm Bottom: 2.7 cm Left/right: 2.5 cm
Line spacing	Single
Justification	Full
Font	Times New Roman (only)
Font size	Title:14 point, bold Authors: 12 point, bold Affiliation:12 point cursive Main text: 12 point Keywords: (3 to 6) 12 point, bold, cursive
Length	250 to 500 words
Presentation	A second page showing data in graphs or tables could be acceptable if the authors consider it beneficial for the review, but should not be referenced in the abstract, since it will not be published in the Book of Abstracts.

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Radiological Protection and Public Health: crossbreeding

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Abstract

This paper summarizes the scope of activities, ongoing experience and current results of the Expert Group on the Public Health Perspective in Radiological Protection (EGPH) of the Committee of Radiological Protection and Public Health, OECD Nuclear Energy Agency. While the prime and general task of the EGPH group is looking at how the public health and radiation protection can better take an advantage of their respective perspectives, the following four areas have been explored in detail: a) exposure to radon; b) justification of medical exposures; c) public health judgement and decision making based on new scientific evidence; and d) management of individual differences. In most of these areas, a targeted telephone survey on public policies in selected countries was used for collecting information from stakeholders (public, consumers groups, public health and radiation protection regulators, governmental bodies, medical practitioners, patients, scientific communities, NGOs, etc.). The presented paper also highlights key issues of collected information and summarises existing approaches and policies.

The case study on exposure to radon collects national information on approaches to the management of domestic radon risks, focusing on the integration of radiation protection and public health aspects (quality of dwellings, overall quality of indoor air, perception of radon levels, position of radon risk in the pool of other risks…).

In the case of justification of medical exposures, the Group studies the applications of the justification principle in opportunistic screenings (responsibilities, management of the situation, risk assessment…).

The precautionary principle and its impact on policy judgement in the light of significant scientific uncertainties can have a large influence on radiological-protection decision making. The case study on public health judgement and decision making based on new scientific evidence is exploring how these uncertainties and lack of scientific evidence are affecting regulatory and policy judgements.

The case study on management of individual differences is exploring how these differences are taken into account when identifying, assessing and managing public health risks in inherently inhomogeneous populations. It looks at different types of rationale used to manage public health risks (e.g. radiation and chemical risks, approval of new pharmaceuticals, management of various toxic agents) focusing on how individual differences (like genetic susceptibilities, age and gender) are taken into account.

KEYWORDS: public health, radiological protection, radon, opportunistic screening, precautionary principle, individual radiosensitivity

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The necessary guidance on the application of JUSTIFICATION and ALARA by the Nuclear Authorities, using "Accountability for Reasonableness" as a decision making process.

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Abstract

In all branches of law, but foremost in international nuclear law, the global economic system brings along a vast record of Soft Law covering General Principles and Standards.

For a part we can find these Soft Law Principles and Standards back in the clothing of hard law, or in the licensing procedures, at the national level.

The larger part however is never "transposed" into national laws and especially the harmonization, the implementation and control of such Principles and Standards remain doubtful.

In this paper the focus lies on JUSTIFICATION and ALARA, as the main nuclear safety principles, accepted world-wide.

The regulatory guidance and demonstration of these Principles, indicating which (numerical) safety levels or safety objectives are mandatory and which are only guidance should be undertaken by the international regulators and authorities, but are often lacking.

It is the aim of this paper to come up with a better procedural framework for a priority setting process by nuclear authorities. Establishing a fair process for priority setting is easier than agreeing on principles. We use the idea of "Accountability for Reasonableness", developed in the field of Health Care Management.

An ideal model of priority setting within the JUSTIFICATION/ALARA approach will need to specify what should be done (i.e. justified ethically) and how it can be done (i.e. based in empirical reality and on benchmarking), to reach optimal levels of nuclear safety.

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The EURADOS/CONRAD activities on radiation protection dosimetry in medicine

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Abstract

This presentation gives an overview on the research activities that EURADOS coordinates in the field of radiation protection dosimetry in medicine.

EURADOS is an organization founded in 1981 to advance the scientific understanding and the technical development of the dosimetry of ionising radiation in the fields of radiation protection, radiobiology, radiation therapy and medical diagnosis by promoting collaboration between European laboratories. EURADOS operates by setting up Working Groups dealing with particular topics. Currently funded through the CONRAD project of the 6th EU Framework Programme, EURADOS has working groups on Computational Dosimetry, Internal dosimetry, Complex mixed radiation fields at workplaces, and Radiation protection dosimetry of medical staff. The latter working group coordinates and promotes European research for the assessment of occupational exposures to staff in therapeutic and diagnostic radiology workplaces.

Research is coordinated by sub-groups covering three specific areas: 1. Extremity dosimetry in nuclear medicine and interventional radiology: this sub-group coordinates investigations in the specific fields of the hospitals and studies of doses to different parts of the hands, arms, legs and feet; 2. Practice of double dosimetry: this sub-group reviews and evaluates the different methods and algorithms for the use of dosemeters placed above and below lead aprons, especially to determine personal doses to cardiologists during cardiac catheterisation, but also in CT-fluoroscopy and some nuclear medicine developments (e.g. use of Re-188); and 3. Use of electronic personal dosemeters in interventional radiology: this sub-group coordinates investigations in laboratories and hospitals, and intercomparisons with passive dosemeters with the aim to enable the formulation of standards.

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Intercomparison on measurements of the Quantity Personal Dose Equivalent HP(d) by Active Persnal Dosimeters

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Abstract

Active Personal Dosimeters (APD) are widely used in many countries, i.e. in the medical field and as operational dosimeters in nuclear power plants. Their use as legal dosimeters is already established in few countries, but will increase in the near future. In the majority of countries, APD have not undergone accreditation programs or intercomparisons.

The IAEA in cooperation with EURADOS organized such an intercomparison exercise using most of the testing criteria as described in two internationally accepted standards (IEC61526 and IEC61283). Additionally simulated work-place fields were used for testing the APD reactions to pulsed X-ray fields and mixed gamma/X-ray fields.

Nine suppliers from six countries in Europe and USA participated with 13 different models in the intercomparison exercise. One of the models was a special design for extremity dose measurements. Irradiations and readout was done by two accredited calibration laboratories in Belgium and France and the French standard laboratory. The final results, as assessed by the irradiation labs and discussed with the APD suppliers were:

- The general dosimetric performance of the tested APD is comparable to the performance of standard passive dosimetric systems
- The accuracy at reference photon radiation, the reproducibility and repeatability of measurements are even better than for most passive dosimeters
- Only 3 devices have given satisfactory results both for 60 kV (RQR 4) and 120 kV (RQR 9) pulsed radiation.

Not all the devices have been designed for any radiation field and the end-user should take into account at least information about the dose equivalent rate and energy ranges before using the dosimeter. The performance results confirm that the IEC standard requirements are adequate but that they can be insufficient for some applications such as pulsed radiation fields.

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Extremity dosimetry in medical applications within Europe: An overview of doses and monitoring practices

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Abstract

Some activities of the EURADOS Working Group 9 (WG9) related to the radiation protection dosimetry of medical staff were funded by the European Commission in the framework of the CONRAD project, Work Package 7. The objective of WG9 was to promote and co-ordinate research activities for the assessment of occupational exposure to staff at workplaces in therapeutic and diagnostic radiology and nuclear medicine. At these workplaces, from the point of view of the individual monitoring for external radiation, the skin of the fingers is generally the limiting organ. Subgroup 1 of WG9 had as main objective the study of the use of extremity dosemeters in medical radiation fields.

The wide variety of radiation field characteristics present in medicine together with the difficulties of measuring a local dose which should be representative for the maximum skin dose using one single detector, makes it difficult to perform extremity dosimetry with an accuracy similar to that of whole-body one. A recent intercomparison organised by WG9 showed that some types of dosemeters significantly underestimate or overestimate skin doses.

Subgroup 1 carried out a thorough literature review on extremity dosimetry issues. It covered diagnostic and therapeutic nuclear medicine and PET, interventional radiology and cardiology, and brachytherapy. It has notably pointed out the consensus about the requirement of regular extremity dose monitoring for nuclear medicine and PET, and the great difficulty of measuring extremity doses for procedures in interventional radiology and cardiology, activities for which routine extremity dose monitoring has been found to be poor.

Furthermore, information on the status of extremity dosimetry in medical applications and associated monitoring practices was gathered from 7 European countries: France, Germany, Greece, Ireland, Poland, Spain and Switzerland. Interpretation of the data was not easy because of the wide range of procedures involved and also because of the lack of criteria for the unification of activities in the medical field. However, the overview

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highlighted fields where there is a greater need for improvement and harmonization.

In this paper, the main results of this work are presented.

KEYWORDS: extremity dosimetry; nuclear medicine; interventional radiology; brachytherapy.