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Le treizième congrès de l'IRPA (International Radiation Protection Association) a eu lieu à Glasgow du 13 au 18 mai 2012.
Ce numéro 4 du Volume 37 des Annales de l'Association belge de Radioprotection reprend des articles avec co-auteurs belges.

Van 13 tot 18 mei 2012 vond te Glasgow het dertiende congres van de IRPA (International Radiation Protection Association) plaats.
Dit nummer 4 van Volume 37 van de Annalen van de Belgische Vereniging voor Stralingsbescherming, herneemt de artikels met Belgische co-auteurs.

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GUIDELINES TO OPTIMIZE EXTREMITY MONITORING AND TO REDUCE SKIN DOSES IN NUCLEAR MEDICINE. RESULTS OF THE ORAMED PROJECT

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Abstract:
ORAMED (www.oramed-fp7.eu) is a European collaborative project developed in 2008-2011 to enhance the safety and efficacy of the use of radiation in medicine, mainly in interventional procedures and in nuclear medicine. This paper focuses on summarising the project guidelines in order to optimize extremity monitoring and to reduce skin doses in nuclear medicine (NM).

NM procedures require handling of radiopharmaceuticals in contact with the extremities. NM radiopharmaceuticals are mostly photon emitters, but mixed photon/beta emitters are used for Positron Emission Tomography (PET) and pure beta emitters for many therapeutic applications. These characteristics lead to difficulties in establishing an appropriate monitoring program. On the one hand, the dosemeter has to be sensitive to a large range of radiation types and, on the other, the dosemeter should be worn close to the most exposed area on the hand. Monitoring of 124 workers from 32 hospitals in Europe highlighted that, in some cases, the maximum skin dose limit is exceeded and that, for the same type of work, there is a wide range of exposures. To complete the experimental observations, a Monte Carlo simulation of some selected typical NM scenarios was undertaken to quantify the influence of different radiation protection means. Based on the results of these studies, it can be concluded that there is a need to perform an appropriate extremity monitoring for NM staff in charge of labeling or injection of radiopharmaceuticals. Guidelines are proposed to correctly estimate hand exposure in NM and to reduce hand doses to an acceptable level.

Key words: extremity dosimetry, nuclear medicine, individual monitoring

Introduction

Nuclear medicine (NM) is a medical speciality based on the use of radioactive substances either for the production of images to diagnose different pathologies or, less frequently, for therapeutic purposes. In recent years the increase of workload at NM departments has called into question whether radiation protection standards for extremities of NM staff has adapted to the current situation. This fact has been reflected on field-related scientific literature.

Published works highlight important common points. Firstly, and especially for therapy procedures, very high finger doses are occasionally found in the literature when radiation protection measures are not optimized. In these cases, finger doses can easily exceed the annual dose limit for extremities (Rimpler *et al.* 2008, Cremonesi *et al.* 2006). Secondly, a wide range of measured doses is observed. Variations on the radiation protection measures, radionuclides and measurement methodologies, among other factors, entail large variability of results, even for similar or equal procedures (Donadille *et al*. 2008). This fact leads to the conclusion that an optimization of the procedures is still possible. The third main point is that the distribution of the dose across the hand is inhomogeneous, with very high ratios between the dose measured in the fingertips - the likeliest position of maximum dose - and the common positions for wearing a routine dosemeter. The range of reported ratios is very wide. Finally, it is clear from the reading of available works, that the use of inappropriate dosimetric material for beta or positron radiation is not rare (Carinou *et al*. 2008). On the other hand, such data diversity makes their analysis difficult to handle, as highlighted by literature reviews, Vanhavere *et al*. (2008), (ICRP 2008).

Aim and outline

The radiation protection of workers in Nuclear Medicine (NM) presents open issues that have not yet been satisfactorily addressed, in spite of growing interest in the subject. As a response to the general problems of radiation protection for medical staff, the ORAMED project (Optimization of RAdiation protection for MEDical staff) (http://www.oramed-fp7.eu/) was founded in 2008 by the European Commission. ORAMED was a collaborative project of the 7th EU Framework Programme, Euratom Programme for Nuclear Research and Training. The project lasted three years and covered the fields of Interventional Radiology and Cardiology and Nuclear Medicine, not only for extremity doses, but also for eye lens doses.

The main results of the ORAMED project can be found in the special issue of Radiation Measurements Journal (Ginjaume *et al.* 2011). The proposed recommendations to optimize radiation protection in interventional radiology and cardiology are presented in Carinou *et al*. (2011) and summarized in Carinou *et al*. (2012).

In the field of nuclear medicine the main objectives were:
- To evaluate extremity doses and dose distributions across the hands of medical staff working in NM departments.
- To study the influence of protective devices such as syringe and vial shields and to improve such devices when possible.
- To propose "levels of reference doses" for each standard NM procedure and to use these for risk assessment and optimisation of working methods.
- To propose a methodology to reduce doses to NM workers.

This paper describes the methodology followed to achieve the proposed objectives, summarizes the main results and presents some guidelines to correctly estimate hand exposure in NM and to reduce hand doses to an acceptable level.

Material and methods

To evaluate extremity doses and dose distributions across the hands of NM medical staff, an extensive measurement program was performed including 124 workers from 32 NM departments in 7 European countries, Belgium, France, Germany, Italy, Slovakia, Spain and Switzerland representing the largest number of collected data on extremity dosimetry in NM. All participants followed a common protocol.

Radiopharmaceuticals: The preparation and administration of both diagnostic and therapy procedures were studied. In diagnostics, radiopharmaceuticals labelled with ^{99m}Tc (pure gamma ray source, emitting a photon of 140 keV) and ^{18}F (positron emitter with a maximum energy of 634 keV) were included in the investigations because of their wide use. For therapeutic procedures the studies were focused on ^{90}Y (high-energy beta emitter with a maximum β^- energy of 2.28 MeV) labeled radiopharmaceuticals such as Zevalin® and DOTATOC.

Measurements: For each radionuclide, preparation and administration to the patient of the radiopharmaceutical were separated. Twenty-two TLDs, calibrated to measure the personal dose equivalent $H_p(0.07)$, were used to evaluate the skin dose at 11 positions on each hand (Figure 1). For most of the operators the measurement was repeated 4 to 5 times. In order to compare the exposure of different workers, individual measurements were normalised to the manipulated activity. The manipulated activity was defined as the activity withdrawn from the elution vial for ^{99m}Tc preparation, the activity in the mono- or multi-dose vial for ^{18}F and ^{90}Y preparation and the total activity in the injection syringe for injection.

The TLDs used by the partners were of different types, either LiF:Mg,Ti or LiF:Mg,Cu,P with thickness ranging from 7 to 240 $mg.cm^{-2}$. For beta and positron radiopharmaceutical only thin detectors (<10 $mg.cm^{-2}$) were used (Carnicer *et al*. 2011b).

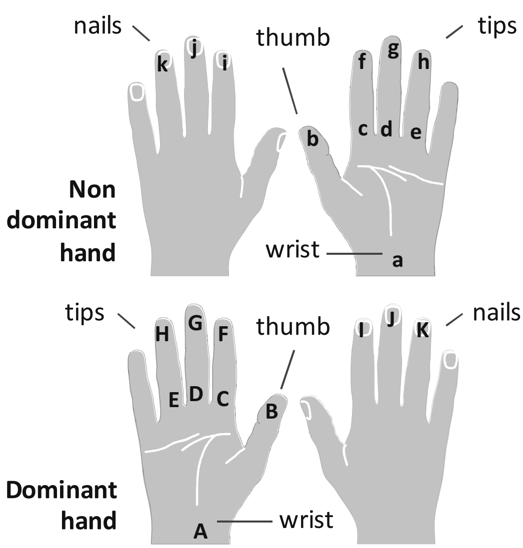
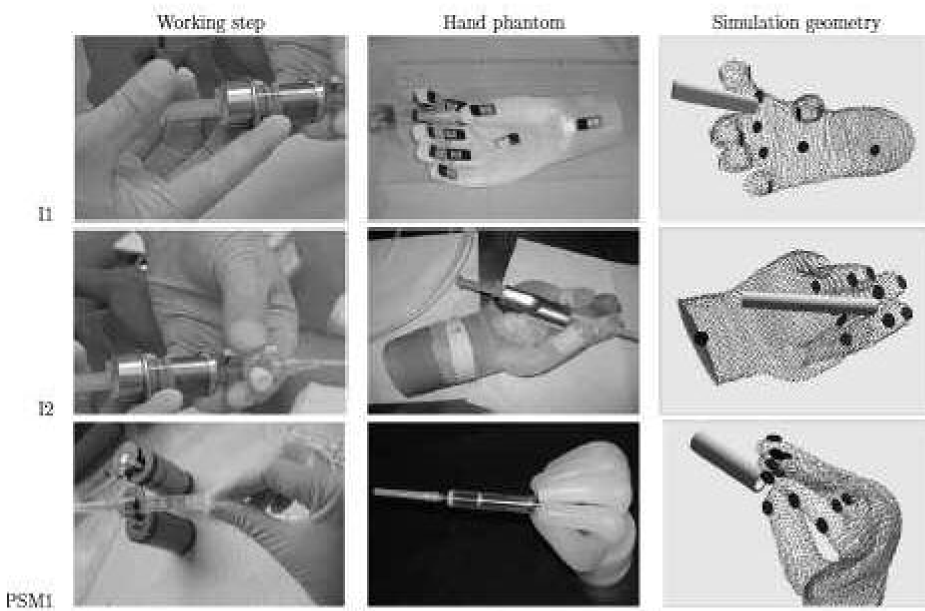


Figure 1: Skin dose measuring positions

***Monte Carlo simulations*:** A set of 6 configurations was defined, representing the most common manipulations carried out during the preparation and injection of radiopharmaceuticals: injecting the radiopharmaceuticals, holding a syringe in hand, by the piston and by the needle, holding a vial in hand and with forceps. Unshielded and shielded (PMMA, Pb, W of different thicknesses) cases were considered for ^{99m}Tc- ^{18}F- and ^{90}Y-labelled radiopharmaceuticals.

Hands were modelled as voxelized phantoms built from paraffin moulding of real hands (Figure 2). As function of the considered radionuclide and configuration, the calculations involved either the transport of photons only or a coupled photon-electron transport. The MCNPX code was used (Pelowitz 2008). These simulation were validated in selected configurations by comparing $H_p(0.07)$ values measured with TLDs on the original hand moulding with those determined by simulation.

MC calculations aimed at better determining the main parameters that influence extremity exposure, the effectiveness of different radiation protection measures, such as the design of shielding, and the degree of variability that could be "intrinsically related" to each monitored procedure.



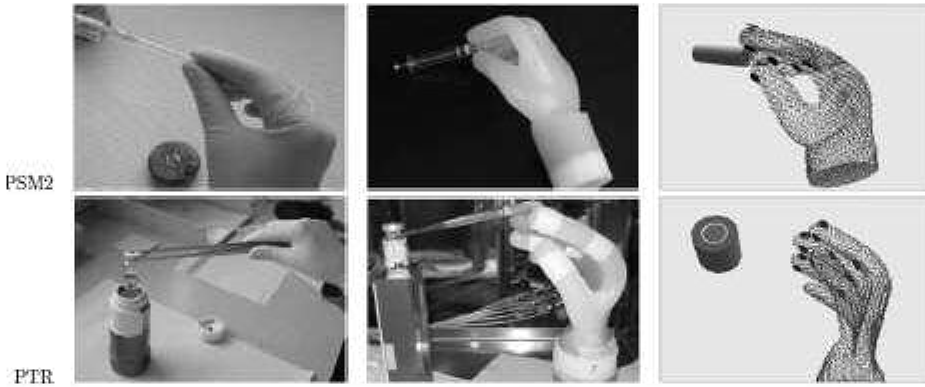


Figure 2: MC Configurations. Left: photographs of selected working steps, middle: paraffin hand phantoms, right: geometry of the simulated hand phantom

Results and discussion

Extremity doses and dose distributions across the hands of NM medical staff

Figure 3 and 4 show the maximum dose for each monitored worker (the worker is represented by a bar) for diagnostics and therapy with ^{90}Y Zevalin® procedures respectively. The first coloured values correspond to the 1st quartile (green), then (in different colours), the 2nd (blue), 3rd (yellow) and 4th (red) quartiles.

Figures 3 and 4 highlight wide ranges of maximum doses measured for identical procedures, which indicate that some workers could potentially optimize their working procedures or habits. Three main factors are associated with workers receiving high doses: working without shielded syringe and/or vial, direct contact with the source container. Some workers associated with very low exposure were found to be related to well-optimized procedures or with the use of advanced techniques, including semi-automatic dispensing tools. From these data and considering the monitored workers workload, it was estimated that 19 % of workers could exceed the maximum skin dose limit of 500 mSv, averaged over 1 cm^2 (ICRP, 2007) and almost 51% of them present estimated annual doses above 3/10th of the dose limit. The most critical situation was found for preparation of ^{18}F, in which 40% of the workers could exceed the dose limit, and 47% could receive a dose higher than 3/10th of the dose limit. In the case of ^{90}Y-Zevalin® procedures, the dose limit is not exceeded because in general the frequency of the procedure is low, but the potential risk of these procedures must not be underestimated, since doses for a single measurement can be very high whenever the radiation protection means are not appropriately undertaken.

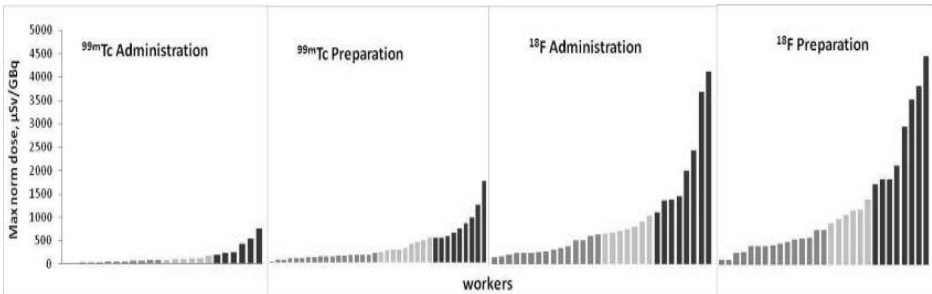


Figure 3: Maximum dose for each worker for diagnostic procedures

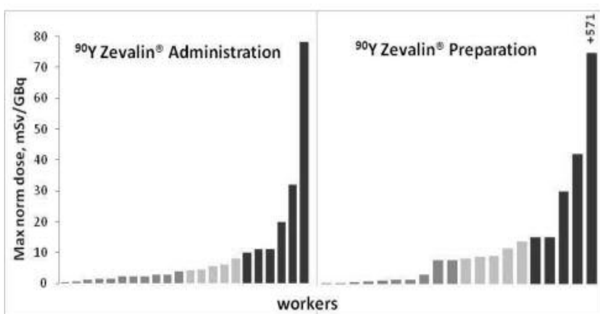


Figure 4: Maximum dose for each worker for ^{90}Y-Zevalin® procedures

Figures 5 and 6 show the frequency of the position where the maximum dose was received for diagnostics and therapy, respectively. For all procedures and when manipulating with shields, the index tip of the non-dominant hand is the position where the maximum dose is most frequently received (from 22% to more than 60%), followed by the thumb of the same hand for almost all procedures (from 7% to 20%). Less frequently, the same positions of the dominant hand were also found to be common positions with maximum dose (up to 10% for most procedures).

There is a general agreement that the fingertips are the most exposed part of the hands (Jankowski *et al*., 2003; Covens *et al*., 2010). However, there is no consensus on which hand and which particular position. From our data, it was observed that the higher exposure of one of the hands is strongly linked to the individual working habits. Nevertheless, this study, based on a large measurement campaign, showed that the fingertips of the non-dominant hand are the most exposed positions, whereas ICRP, based on a thorough literature review, reports that the same fingers of the dominant hand are the most exposed (ICRP, 2008).

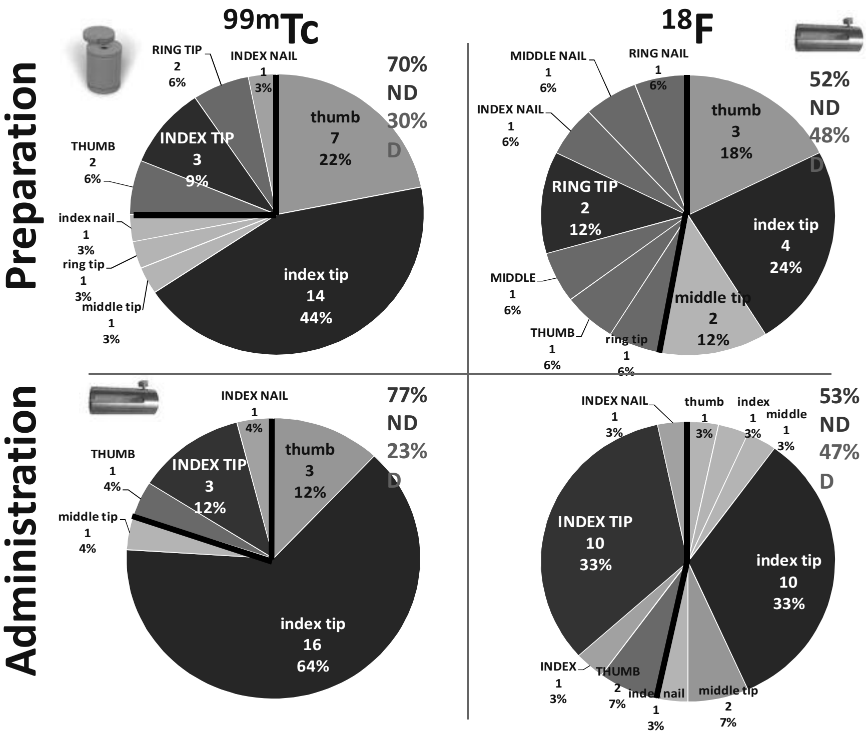


Figure 5: Frequency of the position where the maximum dose was received for each diagnostic procedure when using shielding

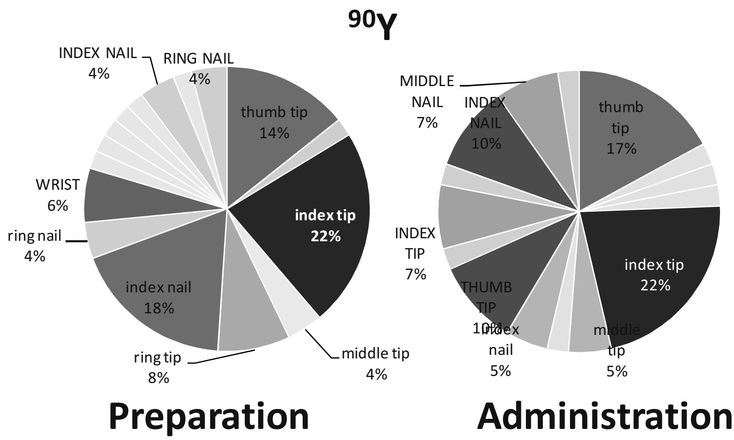


Figure 6: Frequency of the position where the maximum dose was received for 90Y Zevalin® procedures

Tables 1 and 2 show the main results obtained in the ORAMED project compared with previous studies. Comparison of data among different works is a difficult task due to the many variables and parameters involved in this type of measurement, measurement methodologies (detector type, position of the detector/s on the hand...), scope of the measurements (single or multiple radionuclide/s, procedure/s, step/s within the procedure...) and in the expression of the results (how is the dose reported, what other data are given...).

Procedure	Reference	N workers	Measurements per worker	Value (position)	$\langle H_p(0.07)_{max}/A \rangle$ (μSv/GBq)			
					Min	Median	Mean	Max
^{99m}Tc Administration	Carnicer *etal* . (2011a)	32	4 – 5	Max (tip)	10	120	230	950
	Tandon *etal* . (2007)[a]	54	1 – 2	Mean (ring)	5	46	175	999
	Covens *etal* . (2007)[a,b]	5	n.s.	Max (tip)	40	49	50	60
^{99m}Tc Preparation	Carnicer *etal* . (2011a)	36	4 – 5	Max (tip)	30	250	430	2060
	Tandon *etal* . (2007)[a]	54	1 – 2	Mean (ring)	2	46	113	361
	Wrzesién *etal* . (2008)	13	3-4[a]	Max (tip)	30	-	260	2000
	Covens *etal* . (2007)[a,b]	2	n.s.	Max (tip)	20	65	65	110
	Leide-Svegborn(2011)[b]	3	3-7	Max (tip)	20	29	57	121
^{18}F Administration	Carnicer *etal* . (2011a)	30	4 – 5	Max (tip)	140	640	930	4110
	Tandon *etal* . (2007)[a]	3	1 – 2	Mean (ring)	155	218	232	324
	Covens *etal* . (2007)[a,b]	5	n.s.	Max (tip)	210	320	321	530
	Covens *etal* . (2010)[b]	8	5[a]	Max (tip)	200	280	350	750
	Covens *etal* . (2010)[b,d]	8	2-3[a]	Max (tip)	3.5	10	11	30
^{18}F Preparation	Carnicer *etal* . (2011a)	30	4 – 5	Max (tip)	100	830	1200	4430
	Tandon *etal* . (2007)[a]	3	1 – 2	Mean (ring)	65	87	83	98
	Covens *etal* . (2007)[a,b]	2	n.s.	Max (tip)	290	570	570	850
	Covens *etal* . (2010)[b]	2	25 [a]	Max (tip)	90	320	500	1300
	Covens *etal* . (2010)[b,d]	2	10 [a]	Max (tip)	4.5	9	10	18

n.s. Not specified
[a] Values not directly reported
[b] Approximate values (taken from graphs)
[c] Normalized by the eluted activity plus activity manipulated during radiopharmacy work
[d] Automated dispensing and injection system (Posyjet)

Table 1: Comparison of values of hand skin dose in NM diagnostics in several published works. (Adapted from Carnicer et al. 2011a).

Procedure	Reference	N workers	N Measurements	$\langle H_p(0.07)_{max}/A \rangle$ (mSv/GBq) Min	Median	Mean	Max[c]
^{90}Y-Zevalin® Preparation	Rimpler *et al*. (2011)	15	1-5	0.7	8.0	8.0	32
	Rimpler *et al*. (2011)[a]	20	1-5	0.2	7.6	37	570
	Rimpler *et al* (2008)	11	n.s.	2	5.4	-	13(600)
	Geworski *et al*. (2006)	7	n.s.	1.4	-	4.0	8.1
	Cremonesi *et al*. (2006)[b]	n.s.	15	0.1	1.5	1.9	28
^{90}Y-Zevalin® Administration	Rimpler *et al*. (2011)	19	1-5	0.7	2.9	4.1	11
	Rimpler *et al*. (2011)[a]	22	1-5	0.3	3.2	8.2	78
	Rimpler *et al* (2008)	14	n.s.	0.7	1.0	-	7(27)
	Geworski *et al*. (2006)	8	n.s.	0.4	-	3.3	10.6

n.s. Not specified
[a] Data including outliers
[b] Values not directly reported
[c] Values in parenthesis correspond to outliers and are not considered in the mean and median calculation

Table 2: Comparison of values of hand skin dose in NM therapy in several published works. For all works measurements are taken at the maximum (finger tip). (Adapted from Carnicer 2011c).

Table 1 and 2 highlight a large range of measured skin doses for a given procedure, within a specific study. This trend is higher for studies including larger number of workers (Carnicer 2011c; Wrzesien *et al*. 2008; Lindner *et al*. 2003; Tandon *et al*. 2007(for ^{99m}Tc)). Studies with a smaller number of workers and measurements - (Covens *et al*. 2007; Covens *et al*. 2010; Leide-Svegborn 2011; Tandon *et al*. 2007 (for ^{18}F)) present shorter ranges (without considering isolated outliers indicated in parenthesis) and lie within the ranges found by the largest studies. In addition, it is shown, that preparation of radiopharmaceuticals generally involves higher finger doses per activity than administration. In addition, skin dose per activity is also generally higher for ^{18}F than for ^{99m}Tc.

Parameters of influence on skin dose to the hands

The MC simulation sensitivity study revealed that short source displacements (of up to some few cm) and volume changes (of up to 3 ml) can increase the maximum dose by a factor from 3 to 5 depending on the source (Ferrari *et al.* 2011)

Shielding was found to be, both in the MC study and the measurement data analysis, the most influent parameter to reduce hand dose exposure in nuclear medicine. This is in agreement with the conclusions of the ICRP review (2008) and other authors (Martin and Whitby 2003). Even though the use of shields slows down the procedure and can be uncomfortable for technicians especially for heavy and thick shields, their use provide a protection which cannot be replaced by increasing working speed.

MC simulations provided very valuable information in the study of the influence of shielding. The simulations were used to determine what type of material and which thickness represented the best skin dose reduction. Working with a different radionuclide implies different shielding to be used. The recommended shielding can be summarized as follows:

For the injection (concerning the syringe shielding):

- 2 mm W (or Pb) for ^{99m}Tc give a dose reduction of at least 2 order of magnitudes;
- 5 mm W provides up to a factor of 10 in dose reduction for ^{18}F (8 mm W up to a factor 40).
- For ^{90}Y 10 mm PMMA completely shield beta radiation, nevertheless 5 mm shielding of W provides a slightly better shielding cutting down bremsstrahlung radiation too.

For the preparation (concerning the vial shielding):

- For ^{18}F, 3cm of Pb provides 2 order of magnitude on dose reduction. The same attenuation for ^{99m}Tc is obtained with 2 mm Pb. 3 mm Pb lead provides one order of magnitude of additional attenuation.
- For ^{90}Y an acceptable shielding is obtained with 10 mm PMMA with an external layer of a few mm of lead or alternatively 5 mm of W.

As regards the above mentioned reduction factors, it must be kept in mind that the MC calculations correspond to static scenarios and, in practice, the efficiency of the shielding will be lower.

Extremity dosimetry

Based on the analysis of the position of the maximum hand skin dose, it is recommended to place the extremity dosemeter at the index tip or at the base of the index finger of the non-dominant hand. The detector should face the palm of the hand. Comparing the ratios between dose measurements at the maximum dose position and at the usual monitoring positions, correction factors were derived to estimate the maximum skin hand dose from the monitor readings. A factor of 2-3 should be applied for the indextip, a factor of 6 for the base of the index finger and a factor of 20 for the wrist. The latter position is not recommended for NM (Sans-Merce *et al.* 2011).

Guidelines to optimize extremity monitoring and to reduce skin doses in nuclear medicine

From the analysis and interpretation of the data obtained from the measurement campaign as well as from the simulations, the following guidelines are proposed.

1. Extremity monitoring is essential in nuclear medicine.
2. To determine the position for routine monitoring, the most exposed position on the hand for each worker should be found by individual measurements for a short trial period. If for practical reasons, these measurements are not possible, the base of the index finger of the non-dominant hand with the sensitive part of the dosemeter placed towards the inside of the hand is the recommended position for routine extremity monitoring in nuclear medicine.
3. To estimate the maximum dose, the reading of the dosemeter worn at the base of the index finger of the non-dominant hand should be corrected by a factor of 6.
4. Shielding of vials and syringes is essential. This is a precondition but not a guarantee for low exposure, since not all parts (e. g. bottom of the syringe) are shielded during use.
5. The minimum acceptable thickness of shielding for a syringe is 2 mm of tungsten or lead for ^{99m}Tc and 5 mm of tungsten for ^{18}F. For ^{90}Y, 10 mm of PMMA completely shields beta radiation, but a shielding of 5 mm of tungsten provides better protection, as it cuts down bremsstrahlung radiation.
6. The minimum acceptable shielding required for a vial is 3 mm of lead for ^{99m}Tc and 3 cm of lead for ^{18}F. For ^{90}Y, acceptable shielding is obtained with 10 mm of PMMA with an external layer of a few mm of lead.
7. Any tool increasing the distance (e.g. forceps, automatic injector) between the hands/fingers and the source is very effective for dose reduction.
8. Training and education in good practices (e.g. procedure planning, repeating procedures using non radioactive sources, estimation of doses to be received) are more relevant parameters than the worker's experience level.
9. Working fast is not sufficient, the use of shields or increasing the distance are more effective than working quickly.

Conclusions:

The ORAMED project has contributed to enlarge knowledge on hand skin dose levels and dose distribution across the hand in NM by providing the most comprehensive data on extremity exposure of staff in nuclear medical so far. Based on this information and on a thorough sensitivity analysis by Monte Carlo simulation, guidelines for improving protection standards and reducing staff exposures are proposed. Shielding was clearly found to be the most efficient means for dose reduction. For those steps requiring manipulation of bare syringes (e.g. for the activity check), the use of tweezers or automatic systems is recommended, especially for therapy procedures. Training material related to the optimization of radiation protection in nuclear medicine can be down-loaded for free from http://www.oramed-fp7.eu/. In addition, the website provides the instructions to receive an easy tool to estimate hand dose distribution for typical nuclear medicine procedures upon acceptance of freeware license agreement.

Furthermore, the study highlights the importance of extremity monitoring in nuclear medicine and provides specific recommendation to estimate the maximum skin dose.

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DICENTRIC ASSAY IN TRIAGE MODE AS A RELIABLE BIODOSIMETRIC SCORING STRATEGY FOR POPULATION TRIAGE IN LARGE SCALE RADIATION ACCIDENTS

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Abstract

Introduction: Mass casualty scenarios of radiation accidents require high throughput techniques of biological dosimetry for population triage to identify individuals for whom clinical treatment is indicated. To this end the dicentric assay in a triage mode is a very suitable technique. Within the MULTIBIODOSE EU FP7 project a network of eight biodosimetry laboratories has been established with expertise in dose estimations based on the dicentric assay.

Results: In the first task the conventional dicentric assay was tested in the triage mode. Three types of irradiation scenarios were included: acute whole body, partial body and protracted exposure. Blood samples from 33 healthy donors (> 10 donors / scenario) were irradiated in vitro with gamma rays, simulating the 3 different types of exposure and the 3 different doses. All the blood samples were irradiated at the University of Gent, Belgium, and then shipped to the participating laboratories. The dose estimates of acute whole body exposure show a good agreement with actual radiation doses (0.5, 2.0 and 4.0 Gy) for all labs. Most labs could identify correctly the partial body doses at 4 and 6 Gy, but this was not possible at 2 Gy and indicates a need for more cells to be analysed. After protracted exposure, all labs performed these dose estimations well and attained good results at 1.0 and 2.0 Gy.

Conclusions: The results obtained up to now within the MULTIBIODOSE project are very promising for the application of the dicentric assay in triage mode as a high throughput scoring strategy for biodosimetry in case of large scale accidents by a network of eight collaborating laboratories throughout Europe.

Keywords: biological dosimetry, dicentric chromosome, triage mode, radiation accident, radiation dose assessment

Running title: dicentric assay in triage mode

1. Introduction

The dicentric assay has been validated as a reliable biodosimetric tool in small radiation accidents involving a low number of casualties (<100) (Stephan et al 2007, Romm et al 2009). To be prepared for a large scale radiation accident with a large number of potentially exposed persons, there is a need for a high throughput of samples. There have been several strategies developed to cope with this by establishing networks of biodosimetry labs giving mutual assistance (Blakely et al 2009, Di Giorgio et al 2011, RENEB 2012), by developing new scoring strategies (Flegal et al 2010, 2012), by improving the methods with automation (Martin et al 2007, Vaurijoux et al 2009, Jaworska et al 2011) and web based scoring (Livingston et al 2011). To increase the throughput for triage with the dicentric assay a reduction of the number of cells to be scored has been suggested (Lloyd et al 2000). The potential and limits of the new strategy of dicentric scoring in triage mode by a network needs to be examined. A new perspective regarding cooperation between trained laboratories was opened and validated for different radiation exposure conditions.

To explore the homogeneity of dose estimations between 8 European biodosimetry laboratories in the framework of the EU project MULTIBIODOSE it was planned to send blind coded irradiated blood samples and to compare the resulting dose estimations.

The major steps in this interlaboratory comparison can be described as follows: Blood from healthy donors was irradiated in vitro with gamma rays in one laboratory (University of Ghent) and blood samples were sent to the participants. Three different exposure scenarios were simulated, whole and partial body irradiation after acute exposure and low dose protracted exposure, using three different doses per exposure scenario and three repeats per dose point. Scoring was done with two slides of each blood sample in order to obtain information regarding inter- and intra-individual variations. Furthermore, the dicentrics scored from 50 cells in total were to be compared with the results of the first 20 and 30 scored cells of the same slide to get more information about the uncertainties associated with the scoring in triage mode. The aim was to show whether the resulting dose estimations of the participating laboratories were in good agreement or if there was a need for further training and harmonisation of the methods.

2. Material and Methods

In total 33 blood samples from 33 healthy donors were irradiated at the University of Ghent, simulating three different types of exposure scenarios. The blood samples were shipped coded as blind samples in six shipments to the eight participating laboratories and always included one unirradiated shame control. Furthermore each batch of blood samples contained a temperature logger and TLD dosemeter to monitor the temperature and to measure any dose received by the samples during transport. Each shipment contained samples of a high dose rate, a low dose rate and a partial body exposure, thereby giving a total of 27 irradiated samples.

The blood samples were irradiated in vitro in a water bath at 37˚C in a ^{60}Co γ-beam at a dose rate of 0.27 Gy / min for acute whole body (0.5, 2.0 and 4.0 Gy) or partial body exposure (2.0, 4.0 and 6.0 Gy). To simulate partial body irradiations, irradiated blood samples were mixed with sham irradiated controls in a ratio of 1:1. For the protracted exposures the dose rate was 0.0015 Gy / min at 1 Gy (irradiation time 10 h 52 min 14 sec), 0.002 Gy/min at 2 Gy (16 h 05 min 49 sec) and 0.004 Gy / min at 4 Gy (16 h 35 min 41 sec).

Each laboratory set up cultures according to the ISO and IAEA standards (ISO 2004, 2008, IAEA 2011), determined the frequency of dicentrics in the first 20, 30 and 50 cells in two parallel slides (a & b) per sample and then estimated the dose. To minimize uncertainties in dose assessment, each lab used his own calibration curve (Wilkins et al 2009). Therefore, the method of cell cycle control (only complete metaphases in ^{1st} mitoses were scored) depended on the standard protocol already established in each participating lab.

To identify the samples after partial body exposures, the distribution of dicentrics was analysed for deviation from Poisson with the u-test. If the u-test was significant, a partial body dose was estimated together with the irradiated volume of the body using the Dolphin method (IAEA 2011) and assuming a mean lethal dose of 3.5 Gy.

For the dose estimations of the protracted exposures, the G function (IAEA, 2011) was applied, taking the duration of exposure into account and assuming a mean lifetime of breaks of 2 hours.

The dose estimations were performed with the free software CABAS V2.0 (Deperas et al 2007) or Dose-Estimate V4.0 (Ainsbury and Lloyd, 2010). The data were analysed using the chi-squared test for homogeneity to compare the variability of samples within and between groups (sample repeats, doses, irradiation types, labs), the z-test for interlaboratory variability, and General Linear Model Analysis of Variance (ANOVA) with post hoc testing (including Dunnett's test for comparison of doses with controls and Tukey's simultaneous tests for pair-wise comparisons of irradiation types and between laboratories) to investigate the combined dose results from all laboratories. In addition, 2-sample (Youden) plots were prepared to compare the reliability of the dose response among all the labs for each dose compared to 0 Gy in each irradiation category and to allow visual interpretation of the origin of the uncertainties. For the purposes of this intercomparison, laboratories were told whether the samples had been exposed to acute or protracted radiation (as this information is usually available in real life biodosimetry cases), but were not told which or how many samples had been partially irradiated, nor were they given the % partial irradiation. The numbers of correctly or falsely identified samples and the calculated percentage were therefore also analysed for each lab.

3. Results and Discussion

The calibration curves used for dose estimation by each laboratory (Fig. 1, Tab. 1) were compared. There was a good agreement between the curves used and the individual calibration coefficients, with a mean of 0.0230 (range 0.0135 – 0.0375) for the alpha (linear) coefficient and a mean of 0.0588 (range 0.0527 – 0.0759) for the beta (quadratic) coefficient. The standard errors of the coefficients were low for beta, 7 ± 2 % across all labs, but slightly higher for alpha, at 28 ± 4 %. Overall, there were no significant differences between the calibration curves used at each of the laboratories for dose calculations (p all > 0.99).

Lab	C	SE	alpha	SE	beta	SE	radiation quality	dose rate (Gy / min)
Lab 1	0.0002	0.0001	0.0187	0.0047	0.0527	0.0039	Caesium 137	0.42
Lab 2	0.0007	0.0004	0.0375	0.0085	0.0531	0.0054	Cobalt 60	0.30
Lab 3	0.0005	0.0005	0.0142	0.0044	0.0759	0.0027	Cobalt 60	0.50
Lab 4	0.0011	0.0008	0.0228	0.0048	0.0460	0.0020	Cobalt 60	0.28
Lab 5	0.0010	0.0004	0.0338	0.0101	0.0536	0.0044	Cobalt 60	0.50
Lab 6	0.0006	0.0003	0.0135	0.0043	0.0544	0.0034	Cobalt 60	0.25
Lab 7	0.0072	0.0063	0.0538	0.0310	0.0716	0.0163	Caesium 137	0.40
Lab 8	0.0013	0.0005	0.0210	0.0052	0.0631	0.0040	Cobalt 60	1.07

Tab. 1: The coefficients α , β and C ($Y = C + \alpha D + \beta D2$) of the γ-ray dose effect curves of the participants of the intercomparison , SE = standard error

The proportion of M1 and M2 cells at 3 h colcemid were compared and there was very little variation between laboratories, with an average of 95% ± 5% in M1 being observed across the board. This is with the exception of lab 5, for which the proportion in M1 was found to be 74 ± 22%, resulting from a slightly longer and variable culture time of 48 to 50 h.

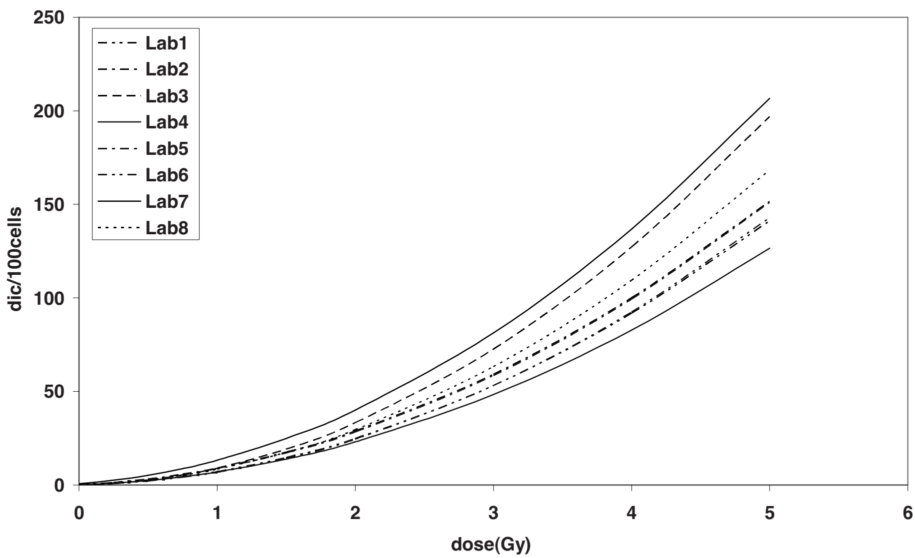

Fig. 1: The γ-ray dose effect curves of the participants of the intercomparison used for dose estimations

Dicentric data were analysed in each individual lab. The chi-squared test for homogeneity was used to demonstrate that, in general, there were no significant differences between parallel slides a and b for either 20, 30 or

50 cells scored, for each lab. There was also generally no significant inhomogeneity within dose categories for each radiation type, and all dose categories were significantly different (distinguishable) from the sham groups. There were exceptions to the above, notably for labs 1 and 2, the results for 0.5 Gy HDR were not statistically different from 0 Gy even for 50 cells ($p = 0.454$ and $p = 0.158$ respectively).

The protracted samples were irradiated on a Monday evening. The acute exposures were always performed on the Tuesday itself, i.e. the same day as when the shipment started. In most cases the blood samples arrived after 24 hours on Wednesday. A strike at Brussels´ airport caused the blood samples from the first shipment (6 samples) to take 48 to 72 h to arrive at their destinations. In the recent literature the impact of transportation time on the yield of dicentrics is under discussion (Moroni et al 2008). To ensure that this did not influence the results of the intercomparison in any way, the numbers of dicentrics scored on these slides were specifically compared to the others in the same irradiation/dose group. The result of this analysis was that there was no evidence of inhomogeneity between these samples, with all p values > 0.86. This indicates that the delay in shipment of these samples did not affect the assay performance.

General Linear Model Analysis of Variance (ANOVA) was carried out to compare the doses estimated for each sample by each laboratory. The different exposure patterns (acute, protracted and partial body), the numbers of cells scored and the sample repeats were also considered. As with the results from the individual labs, the results show that across all labs, there was no significant difference between sample repeats ($p = 0.40$). There was also no significant difference between the dose estimation performed with 20, 30 or 50 cells ($p = 0.07$). Therefore it may be possible to use a number of cells as low as 20 to give a rough indication of absorbed dose. However, the p values varied for individual doses, and on the whole (as expected), dose estimates proved most accurate when 50 cells were used.

The doses estimates for acute whole body exposures show good agreement with the actual doses for all labs (Fig 2). The mean dose estimations were already in agreement for 20 cells and did not change much with increasing cell number (20-30-50cells) at 0.5 Gy: 0.51 Gy, 0.57 Gy and 0.60 Gy ($p = 0.74$), at 2 Gy: 2.21 Gy, 2.20 Gy and 2.22 Gy ($p = 0.64$) and at 4 Gy: 4.26 Gy, 4.33 Gy and 4.34 Gy ($p =0.53$).

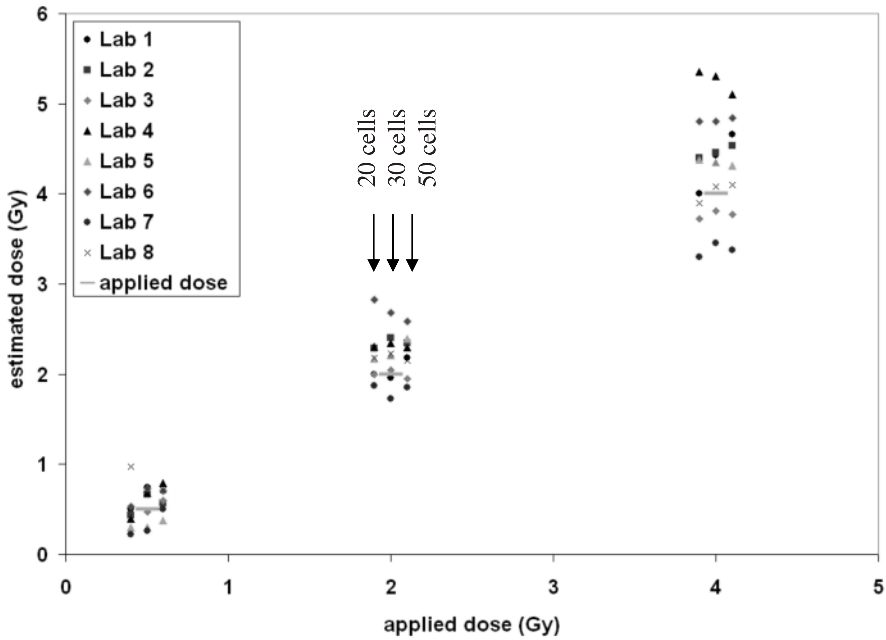

Fig. 2: Dose estimates of 8 laboratories based on 20, 30 and 50 cells (displayed as parallel columns, as indicated at 2 Gy) after simulated acute whole body exposure (HDR) with 0.5, 2.0 and 4.0 Gy

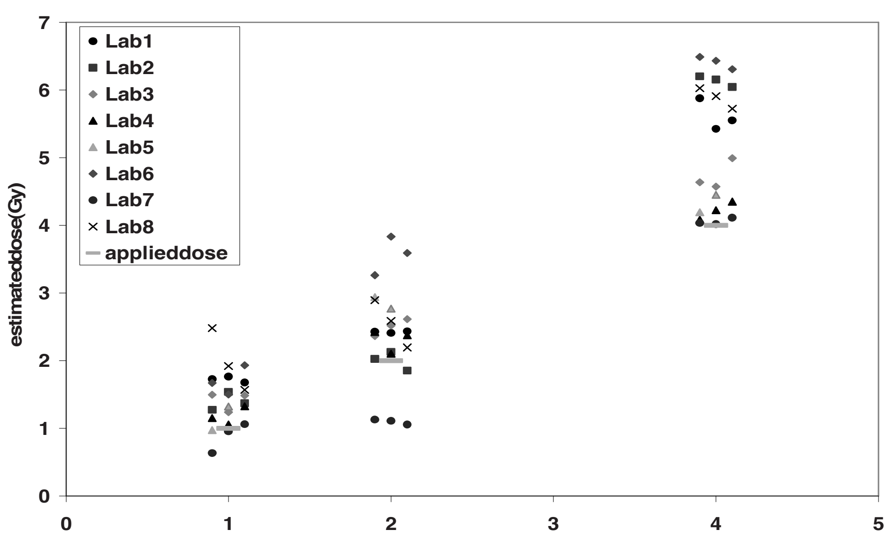

Fig. 3: Dose estimates of 8 laboratories based on 20, 30 and 50 cells (displayed as parallel columns) after simulated protracted whole body exposure (LDR) with 1.0, 2.0 and 4.0 Gy

For this exercise, participants were told which samples were exposed to protracted radiation (LDR), which is similar to real exposure scenarios. Furthermore, it was known, for how many hours the blood had been irradiated, to have a chance to apply the G-function in a correct manner for dose estimation. In general, all labs performed these dose estimations well and received good results for dose estimations of 1.0 and 2.0 Gy. Only the mean (5.3 Gy) for 4 Gy LDR was significantly different from the actual dose ($p = 0.02$). There is a trend of decreasing dispersion with increasing cell numbers (Fig. 3), although the estimates themselves do not really change much with increasing cells numbers (20-30-50); at 1 Gy: 1.37 (± 1.43), 1.41 (± 0.33) and 1.45 (± 0.28) ($p = 0.24$), at 2 Gy: 2.43 (± 0.66); 2.43 (± 0.76) and 2.28 (± 0.71) ($p = 0.48$), and at 4 Gy: 5.19 (± 1.05), 5.15 (± 0.95) and 5.26 (± 0.78) ($p = 0.02$).

The general dose over-estimation may indicate that 50 cells are not sufficient to correctly identify this type of exposure when a protracted dose of 4 Gy of low LET radiation is received. Possibly further low dose-rate experiments are needed to explore the uncertainties associated with the model of the G-function and the reliability of the used alpha terms.

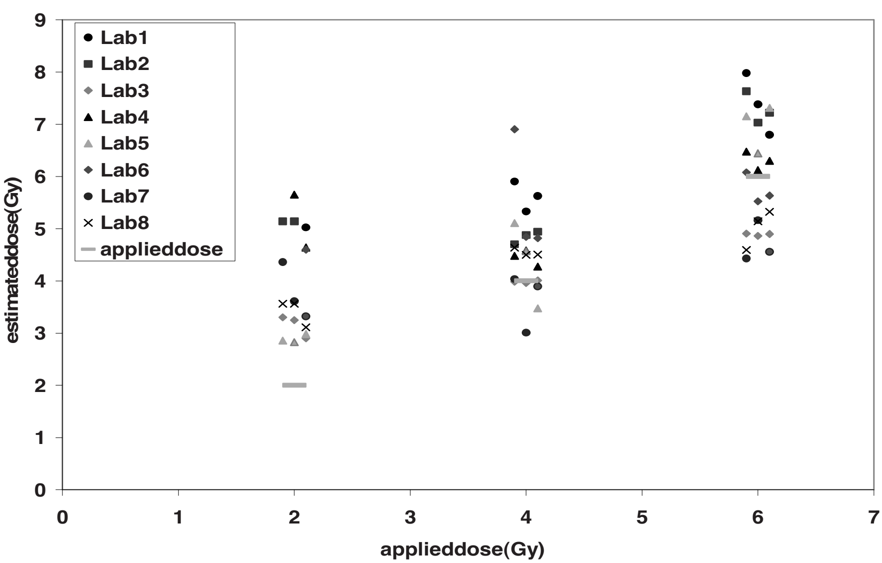

Fig. 4: Dose estimates of 8 laboratories based on 20, 30 and 50 cells (displayed as parallel columns) after simulated partial body exposure (PAR) with 2.0, 4.0 and 6.0 Gy and 50 % irradiated volume.

For simulated 50% partial body exposures to 2.0, 4.0 and 6.0 Gy the results show some variation. Participants were not told which samples were partially exposed – it was left to the individual laboratories to identify these using the u-test and/or variance/mean ratio (Fig. 4). All labs correctly identified all 6 partially exposed samples at 6 Gy when 50 cells were scored; at 4 Gy, the mean number of correctly identified samples was 5.5 out of 6 (range 4 - 6) at 2 Gy, the mean number of correctly identified samples was only 1.75 out of 6 (range 0 - 4). These numbers are very similar but slightly decreased in turn for 30 and 20 cells. The mean dose estimates of all labs together are with increasing cell number (20-30-50 cells) at 2.0 Gy: 1.67 (± 0.62), 1.36 (± 0.61), 2.33 (± 0.20) ($p = 0.02$), at 4 Gy: 3.71 (± 0.87), 3.63 (± 0.90), 4.18 (± 0.72) ($p = 0.54$) and at 6 Gy: 5.16 (± 1.44), 5.78 (± 1.04), and 5.88 (± 0.90) ($p = 0.84$).

No individual lab identified a percentage significantly different from 50%, and, for the data as a whole, there was no significant variation in the irradiated volume calculated for each dose (2, 4 or 6 Gy, p all >0.05). The estimated volumes became more accurate with increasing dose (Fig. 5).

An important conclusion is therefore that while most labs can correctly identify the partial body exposures at 6 Gy and 4 Gy, this was not always possible at 2 Gy when scoring 50 cells. There is a large amount of variability between labs in the numbers of falsely identified partially exposed samples. Therefore calculations based on the three different methods of dose estimation were carried out to estimate the number of cells that would need to be scored in order to correctly identify a dose of 2 Gy in the case of a partial body exposure. Based on the results obtained in this intercomparison, approximately 150 cells would have to be scored in order to identify 50% partial body exposures at 2 Gy with an accuracy of ± 0.5 Gy.

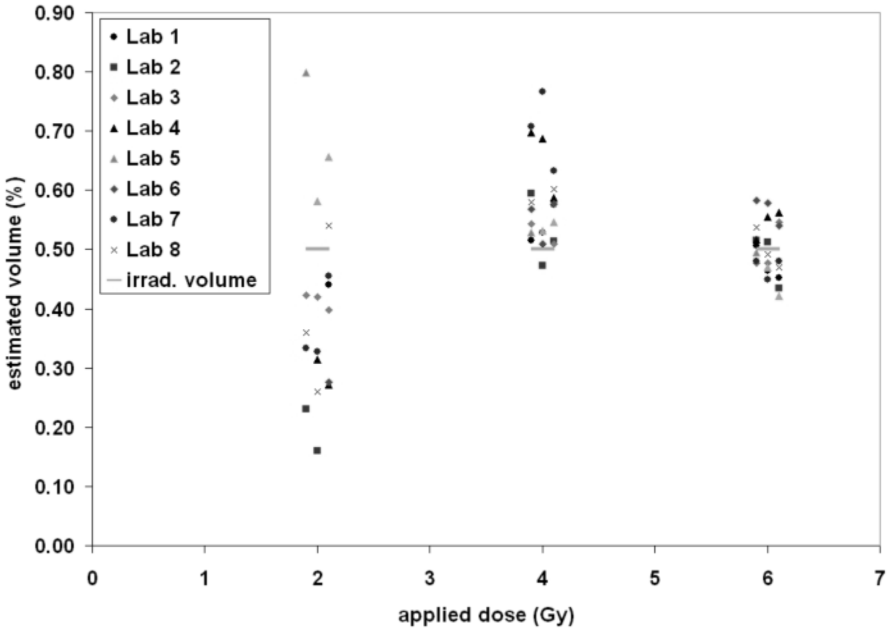

Fig. 5: Estimates of irradiated body volumes of 8 laboratories based on 20, 30 and 50 cells (displayed as parallel columns) after simulated partial body exposure (PAR) with 2.0, 4.0 and 6.0 Gy and 50 % irradiated volume.

Figure 6 shows three-dimensional versions of a Youden plot, comparing z-scores for all of the labs, for 20, 30 and 50 cells. Basically, Youden plots indicates where the uncertainties come from – i.e. whether they reflect random or systematic errors. An ideal plot would be a nice straight surface, through identical points (e.g. (0,0,0)), with most of the values fairly close to zero. Values on the straight surface but far from the origin indicate large systematic errors, values far from the origin and not on the surface indicate large random errors. Figure 6 a) (HDR) compares actual and calculated doses by lab and by the number of cells scored, for the HDR samples. This figure nicely illustrates the spread of dose estimates across the labs, which increases with increasing dose, but decreases (though not to the same extent) with increasing numbers of cells scored. Figure 6 b) (LDR) is fairly flat, but the higher z-values are related to the systematic trend of dose over-estimation with increasing protracted dose. The increased z-values in figure 6 c) (PAR) indicate systematic errors and the bumps indicate random errors, highlighting the need to score more cells when assessing partial body exposures.

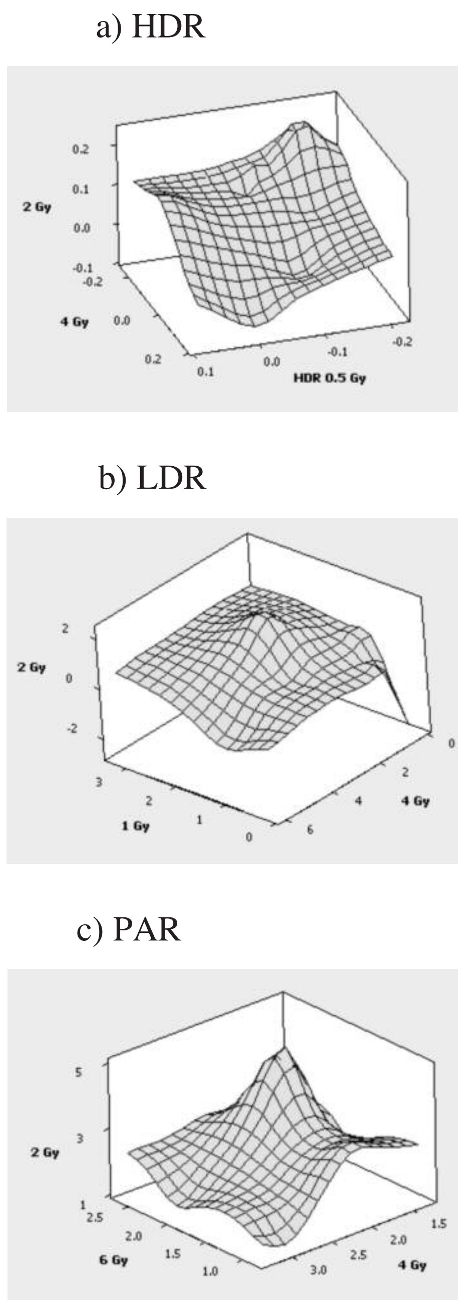

Fig. 6: Youden plots showing the uncertainties caused by random and systematic errors for a) acute (HDR), b) protracted (LDR) and c) partial body (PAR) exposure scenarios.

4. Conclusions

In total, all labs were well trained during this exercise and showed their experience for the different scenarios by using the corresponding cytogenetic tools to provide reliable dose estimations.

While there were good results after acute exposure, there was some unexpected trend to dose overestimations after protracted exposure, which may be explained by uncertainties in the alpha term.

Furthermore, some limitations of scoring in triage mode after partial body exposure were observed, and therefore we recommend to increase the cell number in cases, where there are signs of potential inhomogeneous exposure in order to obtain more reliable data.

With respect to the homogeneity of the conventional scoring results, it can be concluded, that each lab was able to demonstrate great expertise in managing the biological dosimetry challenge of this exercise. In the frame of the MULTIBIODOSE project, further investigations with these samples will be performed in the near future to improve the automated scoring procedure and to validate new scoring strategies.

5. Acknowledgment

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DEVELOPMENT AND DISSEMINATION OF ALARA CULTURE

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Abstract
This paper, elaborated by a working group from the European ALARA Network (EAN) discusses the elements that constitute ALARA culture, its current status in relation to the various exposure situations, and the role of networks to further develop and disseminate it.

Key Words: ALARA, Culture, Optimisation, Network

1. Introduction

ALARA culture is at the heart of radiation protection culture and is based on the hypothesis of a linear dose-effect relationship without a threshold for stochastic effects. It should result in attitudes and behaviours of individuals and organisations, which are always committed to searching for an acceptable level of risk taking into account societal and economic factors.

The need to further develop and disseminate ALARA culture comes at a time when there is an increase of the awareness of risk, a constant development of scientific knowledge about radiation health effects [1], the introduction of new exposure situations, and an increase in the number of applications of ionising radiations.

2. The ALARA principle

Justification of radiation exposures, optimisation of radiation protection and application of individual dose limits are the three radiation protection principles, as adopted for the first time in ICRP publication 26 [2] and incorporated in the subsequent Commission's recommendations [3, 4]. Publication 103 states that optimisation of protection is the process by which *"the likelihood of incurring exposures, the number of people exposed, as well as the magnitude of their individual doses should be kept As Low As Reasonably Achievable taking into account economic and societal factors"*[4].

The principle of optimisation of radiation protection is a direct consequence of the adoption of the linear dose-effect relationship with no threshold for "stochastic effects". It resulted in a search for risk reduction whatever the level of exposure. The wording of the ALARA principle has evolved through the various ICRP publications, integrating the question of how far the risk should be reduced. At the beginning, the Commission proposed a radiation protection philosophy based on a minimum or even zero level of risk. This philosophy was expressed as a recommendation to "reduce doses to the lowest possible level" [5]. In 1959 the initial wording changed [6] to "as low as practicable" and in 1966 to "as low as readily achievable economic and social considerations being taken into account" [7]. In its 1990 Recommendations [3], ICRP introduced the current wording of the optimisation principle, known as the "ALARA" principle – As Low as Reasonably Achievable. The acronym "ALARA" has been used for more than 20 years by radiation protection professionals. It is considered that the two expressions – optimisation of radiation protection and ALARA - are synonymous and interchangeable [8].

The objective of implementing ALARA is to reach an 'acceptable' level of risk, below the dose limit which is the upper bound of the 'tolerable' level of risk. ALARA is an obligation of means, and not an obligation of results, in the sense that the result of ALARA depends on processes, procedures, and judgments and is not a given value of exposure. The acceptable level of exposure depends on the exposure situation as well as the societal and economic considerations.

According to ICRP 101 [9], optimisation is a frame of mind, always questioning whether the best has been done in the prevailing circumstances. It requires a forward-looking iterative process aimed at preventing exposures before they occur. It is continuous, taking into account feed-back experience as well as technical and socio-economic developments. It requires both qualitative and quantitative judgments.

3. Why think about "ALARA culture"?

The European ALARA Network (EAN) has been discussing the issue of "ALARA culture" for a long time. A definition was proposed during the 10th EAN Workshop (Prague 2006) as follows [10]:

"ALARA culture is a reference framework, a state of mind and attitude

- *Allowing an individual and/or an organisation to act in a responsible way in order to manage radiation risks and giving radiation protection the priority it should have;*
- *Characterised by risk awareness, balanced judgement of risks and benefit, and the capability to develop and use required skills and tools for risk assessment and management, balance of resources and economic and societal considerations;*
- *Realized through transdisciplinary education and training tailored at each level;*
- *Supported by management commitment, guidance and supervision of competent authorities on European and national level;*
- *Making use of a clear definition of responsibilities.*

It should have a continuous character covering all processes where radiation protection is involved. It should have full support of authorities and professional organisations while systematically integrated in continuous quality improvement".

At the IRPA 12 Associate Societies Forum held in Buenos Aires in October 2008 [11], an IRPA working group on "Improvement of the Radiation Protection Culture" was launched with the aim of preparing IRPA Guiding Principles on that topic. EAN gave its support to the work of IRPA, focusing on the contribution of ALARA to radiation protection culture. A dedicated EAN working group on ALARA Culture[1] was then set up to maintain and further develop a high level of radiation protection by:

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[1] Members of the EAN Working Group on ALARA culture are the following: *Sotirios ECONOMIDES (GAEC, Greece), James GEMMILL (SEPA, UK), Frank HARDEMAN (SCK/CEN, Belgium), Bernd LORENZ (GNS, Germany), Cristina NUCCETELLI (ISS, Italy), Serena RISICA (ISS, Italy), Caroline SCHIEBER (CEPN, France), Annemarie SCHMITT-HANNIG (BfS, Germany), Fernand VERMEERSCH (SCK/CEN, Belgium), Angela WRIGHT (SEPA, UK).*

– promoting ALARA culture in all fields of application,
– implementing the ALARA principle into practice, and
– analysing feedback from implementing ALARA in various sectors.

This paper presents a synthesis of the main elements contributing to the dissemination and development of ALARA culture.

4. Some elements of ALARA culture

Many elements contribute to a good ALARA culture. Some examples are presented below.

Attitudes and behaviour

Fundamental elements of the ALARA culture are the attitudes and behaviour of the relevant persons towards radiological risk, which are influenced by different cultural backgrounds, personal opinions, existing economic and social conditions or exposure situations. This can explain the differences observed in the degree of implementation of ALARA between different exposure situations or, even within a same type of exposure situation, between individuals, organisations and countries.

Positive attitudes towards radiological risk should include at the individual and/or organisational level:

– a questioning attitude (e.g. did I do what I could to save doses? is the management committed to the introduction of new technologies to save doses or prevent accidents?,...);
– openness and transparency (e.g. open to changing habits, reporting mishaps, explaining radiation protection options,…);
– commitment to dose reduction (e.g. appropriate individual behaviour in the presence of radiation sources, willingness to invest in protection measures,…).

Radiation risk awareness

Risk awareness is the basis of ALARA culture. There is thus a need to reach a common understanding of radiation risk among all the stakeholders involved in the exposure situations. The degree or level of knowledge has to be adapted to the situation, the level of responsibility, the required competences in radiation protection, etc. Therefore, various methods of raising risk awareness may be appropriate: education, training, continuous professional development, communication and information.

Stakeholders engagement and participation

The efficiency of an ALARA-oriented radiation protection system strongly depends on the engagement and the participation of the stakeholders involved. Different categories of stakeholders can be identified whose main roles and responsibilities in the ALARA process are the following.

Competent authorities are responsible for introducing special optimisation provisions in national legislation according to international safety standards (IAEA, EC). Moreover, they should establish and apply appropriate methodologies for the verification of ALARA implementation and to issue recommendations and take enforcement actions if required. They set the regulatory objectives for ALARA. Regarding the relationship with the public, they should not only provide transparent information, but also facilitate public involvement in the decision making processes.

Licensees have to show their commitment to ALARA through an adequate organisation, facilitating implementation of the ALARA process, allocating necessary resources, providing training at all levels of the organisation (from senior management to shop floor). They should establish and implement an effective radiation protection management system. Clear management support must exist to translate the regulatory objectives into reality. Therefore, distribution of responsibilities is fundamental for the effective implementation of ALARA. People involved should be well aware of their role and duties and act accordingly.

Manufacturers, suppliers and designers need to ensure that the design and construction of facilities, equipments or sources are based, not only on requirements and limitations introduced by national legislations, but also on considerations about optimisation of radiation protection for their full life cycle (installation, operation, dismantling).

Radiation protection professionals are responsible for the design, establishment, implementation and surveillance of radiation protection systems which are ALARA-oriented. They have a major role in stimulating and supporting ALARA attitudes and initiatives. Moreover, they should register possible non-compliances, propose corrective actions or improvements and evaluate related results. These non-compliances should be appropriately turned into lessons learnt.

Professional associations have a role in the dissemination of ALARA culture among their members, for example by providing a forum for exchange of experiences, elaborating radiation protection guidance or protocols specific to their field of activities, etc.

Exposed workers are responsible for properly applying the established ALARA procedures after having received the appropriate training. They should have an attitude towards dose reductions for themselves as well as their colleagues. They should not only follow given guidelines and protocols but also identify and report possible problems, as well as applying the required corrective measures. They should participate in the continuous improvement of radiation protection providing practical feed-back.

The public should be allowed to take a proactive role in decision making regarding their protection against ionising radiation. While consultation processes are already implemented in several countries, this approach needs to be applied more often. This will lead to clearer decisions agreed by the public. Therefore, initiatives should be further developed to facilitate an improvement of risk awareness and the radiation protection knowledge of the public.

5. Challenges related to ALARA culture

Depending on the exposure situation, the current status of ALARA culture varies significantly:

- In the *nuclear industry*, ALARA has been applied for more than 20 years, resulting in a significant reduction of occupational collective doses. However, the ageing of existing installations, and a large-scale retirement of nuclear workers requires a new focus on maintaining and expanding ALARA culture. In parallel, new nuclear installations (nuclear waste disposal, nuclear power plants, research reactors, etc.) will be built in the near future, requiring the introduction of ALARA at an early design stage, and decommissioning activities will increase in parallel.
- In the *NORM industry*, there has been a continued increase in radiation risk awareness, and elements of ALARA culture have been introduced. The new regulations in this sector (like the IAEA and EURATOM Basic Safety Standards at the final approval stage) will play an important role in this process.

– Regarding the *medical sector*, occupational and patient exposures have to be considered, taking into account benefits and risks for the patient. An increasing awareness of the importance of radiation protection is observed within the medical profession [12]. However, efforts still have to be made to disseminate ALARA culture more widely, as a huge increase in the use of radiations for medical purposes has been seen in many countries.

– For *existing exposure situations*, like radon in dwellings or phosphogypsum landfills, the practical implementation of optimisation of radiation protection is relatively complex. It needs the involvement of new stakeholders for which the first step is to be informed about radiation risk and ALARA philosophy.

– In *emergency exposure situations*, according to ICRP, optimisation of protection also applies for public and worker exposures. However, due to the complexity that arises in emergency situations, ICRP recently recommended [13] that optimisation should be integrated into the planning stage of protection strategies as well as during the implementation of emergency response.

6. Role of networks in the dissemination of ALARA culture

Several actors, addressing various stakeholder groups, play a valuable role in the dissemination of elements of ALARA culture; like regulators, education and training organisations, professional organisations, networks, etc. They use a variety of tools, such as symposia, workshops, publications, research projects, web sites, discussion forums, etc.

Several types of network involved in or connected to radiation protection exist, at national, or international levels, like professional societies (e.g. medical physicists, industrial radiographers, radiation protection professionals, etc.) or associations/NGO (e.g. patients, public, environmental associations, etc.). They group together various stakeholders and competences, with the same objectives.

The value of these networks for ALARA culture dissemination is to provide a platform to exchange views and experience and to create relationships. They can also contribute to creating knowledge, providing education and training, and identifying and harmonising good practices.

In particular, the European ALARA Network (EAN), as well as related ALARA networks, such as the European Medical ALARA Network (EMAN) and the EAN NORM net contribute to the development and dissemination of ALARA culture.

7. Conclusions

The continuous technological developments in ionising radiation applications and the increasing number of exposure situations highlight the need for further actions to develop and disseminate ALARA culture. At the same time, the number of radiation protection specialists with relevant knowledge and experience is decreasing due to retirement.

Therefore, there is a need to re-establish the elements that constitute ALARA culture (exposure situations, attitudes, responsibilities, etc.) in order to facilitate its practical implementation. That's why the elements presented in this paper will be further elaborated by the EAN working group on ALARA culture in a publication under preparation on "Optimisation of radiation protection (ALARA): a practical guidebook" [14].

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The Fukushima Accident: Reflection in the Media and the Public Opinion in Belgium

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Abstract

This paper analyses the impact of the accident in Fukushima in the Belgian media and public opinion. We study how mass media reported about the accident in Japan and how the public opinion related to nuclear energy changed. The research methodology consisted of: i) content analysis of two quality newspapers in Belgium, covering the first two months after the accident; and ii) public opinion research, based on more than 1000 personal interviews conducted in Belgium in the third month after the accident. The results show that the accident induced enormous media coverage in the first weeks after the accident, with focus on many different topics; yet, attention decreased with time and narrowed down to the future of nuclear, safety and crisis management aspects. It is also argued that historic nuclear accidents became part of the collective memory influencing media reporting and public opinion. As expected, the Fukushima nuclear accident has induced changes in the public opinion and atitudes towards nuclear energy.

Keywords: Fukushima nuclear accident, media reporting, public opinion

1. Introduction

Nuclear accidents have a strong impact on the public opinion and often lead to political discussions about the use of nuclear energy for power generation. In this context, media play an influential role in shaping public opinion about nuclear energy. Media do not only report about public issues, but they also have the power to influence people's opinion. This influence was pointed out already in 1922 by Walter Lippmann (1922). Further studies suggest that the salience of issues in the media reporting influences public opinion and even the behaviour of the people (Barnes *et al*, 2008). When mass media report intensively about a certain topic, the people receiving the media information will consider this topic as important (Cohen, 1985; McCombs and Shaw, 1972). Moreover, numerous studies from political and risk research established strong correlations between media and public priorities (for overview: McCombs and Shaw, 1993). Some particularities can be mentioned as regards media reporting and public opinion about the nuclear accidents and nuclear energy.

Information about the nuclear domain is not directly experienced, but rather learned through elite discourse and communication in the media (Boomgaarden and de Vreese, 2007; Perko *et al*., 2012). Elite discourse is in turn driven by public opinion. For instance, the experience after the accident in Chernobyl showed that nuclear accidents have a strong impact on the public opinion and often lead to political decisions related to nuclear programs (Cantone *et al*., 2007)

At the same time, media are usually more interested in politics than risk, in simplicity than complexity, and in danger rather than safety issues. A nuclear accident is extremely newsworthy, since it is strongly feared, it has catastrophic potential, and it can have long term consequences that usually exceed the geographical boundaries of the radioactive contamination. At the same time, it is an event that can be personalised, and for which politicians are used as a main source of information (Perko, 2011; Perko et al., 2012). Dramatic and extraordinary real-world events are reported in the media and by itself have the power to impact on public opinion and to cause shifts in public attitudes (Boomgaarden and de Vreese, 2007).

Another important point is that the nuclear accidents at Chernobyl or Three Mile Island became part of the collective memory and as such, linked to media reporting about any nuclear event (Boomgaarden and de Vreese, 2007; Greenberg and Truelove, 2011; Triandafyllidou, 1995; van der Brug, 2001; Zorkaja, 2006). Linder (2000) compared the perception of the Chernobyl accident with other non-nuclear disasters and found that other human-made or natural disasters "*tend to be accepted by the public much more readily"* and are relatively quicker forgotten in the media coverage (Lindner, 2000, p.282).

Most of the scholars exploring media reporting about nuclear accident report, directly or indirectly, the changes in the public opinion and the changes in the public acceptability of nuclear energy after the accidents. It is confirmed, that nuclear accidents reduce public support for nuclear energy and increase opposition (Boomgaarden and de Vreese, 2007; Greenberg and Truelove, 2011; Lindner, 2000; McDermott, 1982; Perko et al., 2010; Zorkaja, 2006).

Opinion polls show that public support for nuclear power has declined after the Fukushima nuclear accident, not only in Japan, but also in other nations around the world (Ipsos MORI 2011; Asahi, 2011; Ramana, 2011). People may oppose nuclear power for a variety of reasons, for example perception of nuclear technology as too dangerous. This paper reports on the role and principles of media and journalism with regards to the Fukushima nuclear accident and on the public opinion on issues related to the accident and to nuclear energy; the study of the causal link between the nuclear accident, media reporting and public opinion is beyond the scope of this paper.

The media analysis was done for the Belgian media reporting about Fukushima nuclear accident in the first two months, while the public opinion in Belgium was measured after this media exposure. The next section elaborates on the methodology used; the subsequent section reports on selected results and the final section summarises the conclusions.

2. Methodology

2.1. Media content analysis

The newspapers included in the analysis (Perko *et al.*, 2011) were the Belgian newspapers "Le Soir" (French language) and "De Standaard" (Dutch language). The media news was obtained from press clippings by "Media data base at University Antwerp - MEDIARGUS" for the period between the 11th of March and the 11th of May, 2011. This time sampling of two months was focused on the "critical discourse moments", which made the nuclear issue visible in mass media.

The articles coded were either directly or indirectly related to the Fukushima nuclear accident and were collected by the following keywords: "Fukushima" and "nuclear*". Every article was coded by two independent coders for each language group. In case of disagreement, the master-coder decided the final code based on a discussion. The Krippendorf's inter-coder reliability was calculated.

Once the articles were selected according to the rules each article was assigned a number of codes as prescribed in a codebook.

2.2. The public opinion survey

Since 2002 the Belgian Nuclear Research Centre SCK•CEN conducts periodical large-scale (N> 1000) public opinion surveys among the Belgian population (Perko *et al*., 2010; Turcanu *et al*., 2011; Van Aeken *et al*., 2007). The data collection method employed is Computer Assisted Personal Interviewing, consisting of personal interviews of 30-45 minutes carried out at the home of the respondent, the answers being directly recorded on a portable hard disk. The field work is performed by a market research company with professional interviewers.

The 2011 edition of the survey (Turcanu *et al*., 2011) included, among other, questions on the general attitude towards nuclear and the relevance of the accident in Fukushima for Belgium. The field work was carried out between 25/05/2011 and 24/06/201. The population sample consisted of 1020 respondents and is representative for Belgium adult population (18+) with respect to sex, age, region, province, habitat and social class.

Most questions in the survey were formulated as statements, to which the respondent could answer using a five point Likert-scale (e.g. <strong disagreement, disagreement, undecided, agreement, strong agreement>), plus a sixth category (<no answer/don't know>). The latter answering option was allowed, but not encouraged.

3. Results

3.1. Media reporting about the Fukushima nuclear accident

3.1.1. Media attentiveness to the Fukushima nuclear accident

To identify the statistical signature of the Fukushima nuclear accident we analysed the media the outburst of attention and the decay in the rate of attention. The goal was to identify the accident as a topic in the media agenda and to determine how long the Fukushima nuclear accident was part of the media agenda.

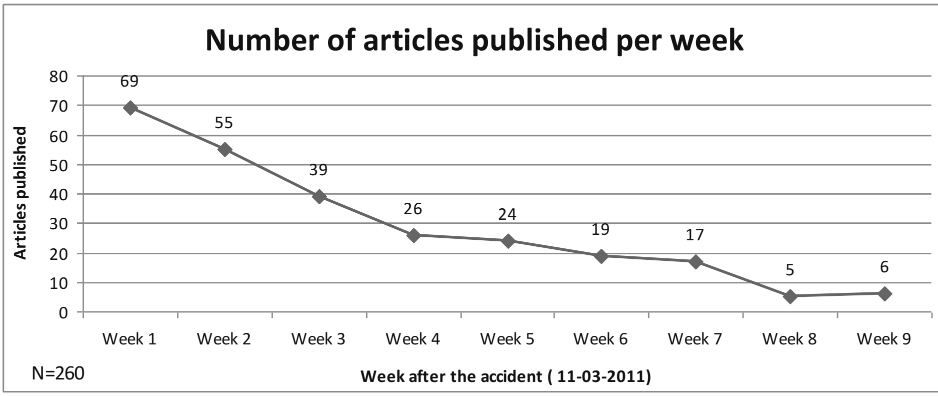

Figure 1: Number of articles published per week in De Standard and in *Le Soir*

To exclude the drops in media attention on Sundays and public holidays the frequency of published articles was calculated per week. Figure 1 clearly shows the explosion of media attention in the first week: the two newspapers published in total 69 articles, with 55 articles related to accident following in the second week. The rate of attention decayed to 6 articles in the ninth week after the accident in Fukushima.

The Fukushima nuclear accident was newsworthy information for the media, since it was an extraordinary event, new or unusual information, conflict was present, drama, tragedy, presence of elite or celebrities, the situation could be personalized and it evoked emotional response. Media also have to fulfill the economic aspects of publishing or broadcasting, with the "bad news is good news" slogan being a well-known phenomenon in journalism and from this point of view the Fukushima nuclear accident was newsworthy. However, the nuclear accident attracted a lot of media attention in the first weeks; afterwards the attention monotonously decreased.

3.1.2. Focus of the media articles related to the accident

The analysis of the main focus of the articles allowed identifying the main challenges of media communication in case of a nuclear accident and the focal point of the media. We investigated what media wrote about related to the nuclear accident, since the media may address an event from different perspectives. The categories used to describe the focus of the articles are summarised in the following.

The category *'Technical aspects'* contained all articles that dealt with the technical aspects of the accident, e.g. technical data about the state of the reactors or the spent fuel ponds. All articles about emergency management and protective actions for people, the food chain or the environment were categorized as *'Crisis management'*. *'Affected inhabitants'* contained all articles that described the situation of people that were victims of the accident. *'International reaction'* presented all articles that described an international reaction on the Fukushima nuclear disaster. Articles on the *'Safety/Risk aspect'* described the possibility of an accident, the probabilistic estimations of accidents in NPP's or referred to the stress tests.

'Information exchange' contained all articles that described the problems with the information exchange. The category *'Future of nuclear energy'* included all articles reporting about decisions or discussions of (international) governments towards the choice of nuclear energy in the future. *'Energy consumption or supply'* addressed the articles about the energy consumption and/or energy supply, including discussions about the policy of electricity suppliers or operators. The articles that discussed whether there is someone to blame belonged to the category '*Blame*'. *'Economic impact*' contained all the articles that discussed the effects of the Fukushima accident on the national or international economy. Figure 2 depicts the percentage of articles (from the total articles published in *Le Soir* and *De Standaard*) reporting on each of these focus points.

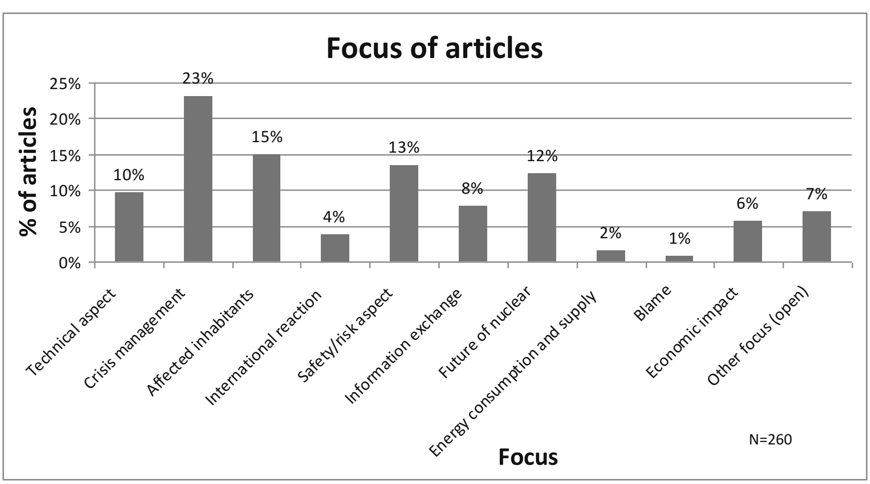

Figure 2: Focus of the articles

We can conclude that the main focal point or the articles was the crisis management of the Fukushima nuclear accident (see Figure 2). 23% of the newspaper articles focused their attention on the emergency management and the protective actions for the people, food chain or environment. 15% of the articles described the situation of people who were victims of the nuclear accident. Interestingly, there were only a few articles that focused on '*blame*' (1%), '*international reaction*' (4%) and '*energy consumption and supply*' (2%).

The detailed analysis of the focal interest of the media revealed the changes in media attention towards different subjects through time in the weeks after the accident. In the first weeks media focused on many different topics, from technical aspects, crisis management, safety risk aspects to energy consumption and supply. Eight weeks after, the media focused their attention to a limited number of topics. In the ninth week after the accident half of the articles focused on the future of nuclear energy, 33% on safety and risk aspects and 17% on crisis management.

3.1.3. Conflict and disagreement related to the accident

In order to identify the existence of conflicts we investigated whether the media reported about conflicts or disagreements related to nuclear emergency. Conflict stories involve a conflict between people/groups/parties/countries. Such stories contained an explicit mention of the fact that there was disagreement about the issue (e.g. nuclear energy, emergency management, monitoring). This disagreement was expressed in words (e.g. contradictory positions or claims) or in deeds (e.g. protest, stigmatisation).

The results presented in Figure 3 show that the amount of articles reporting on conflictual issues had an erratic course: it fluctuated in the weeks after the accident between 20% and 41%. At some points in time there were more articles describing conflicts than at others. One remarkable peak occurs in week 7, the same week in which the accident in Chernobyl was remembered all over the world. More than 40% of the articles published in this week contained a conflict or disagreement.

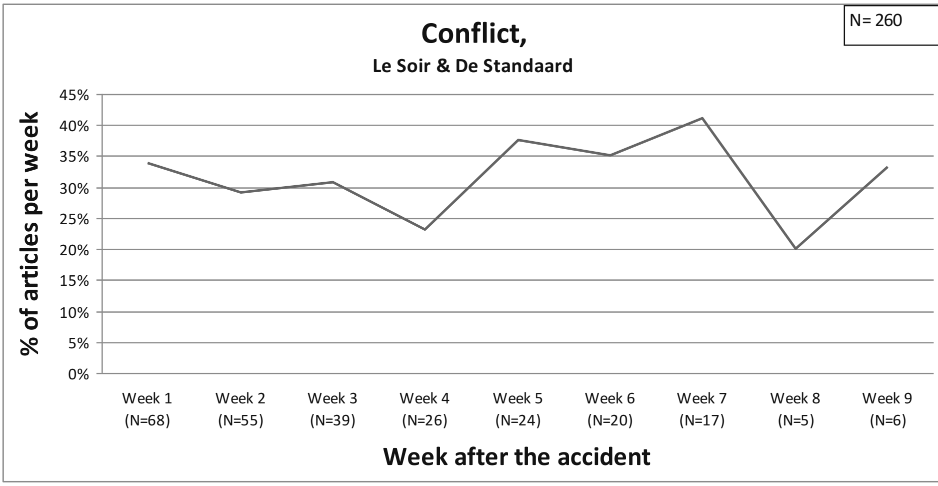

Figure 3: Conflict or disagreement in the articles per week for both newspapers (cumulated)

3.1.4. Article orientation toward nuclear energy

The variable coding the orientation of the article towards nuclear energy explored the way of journalistic reporting about nuclear energy and the arguments used. This refers to the subjective intention of the author or newspaper policy to expose the arguments in favour or against nuclear energy. The articles that presented an opinion about nuclear energy were categorised as 'positive', 'negative' or 'balanced'. To classify a media text as balanced implied that both pro and contra arguments and statements concerning the nuclear energy were equally presented in the article, without a preference for one; therefore the article was coded as a balanced article. The other two options, being pro and contra nuclear energy, were not balanced, but biased towards one orientation.

The results of media analysis show that the overall orientation of the published articles towards nuclear energy was neutral. This means that most articles did not really address the topic of 'good or bad' and that they did not express an opinion about nuclear energy.

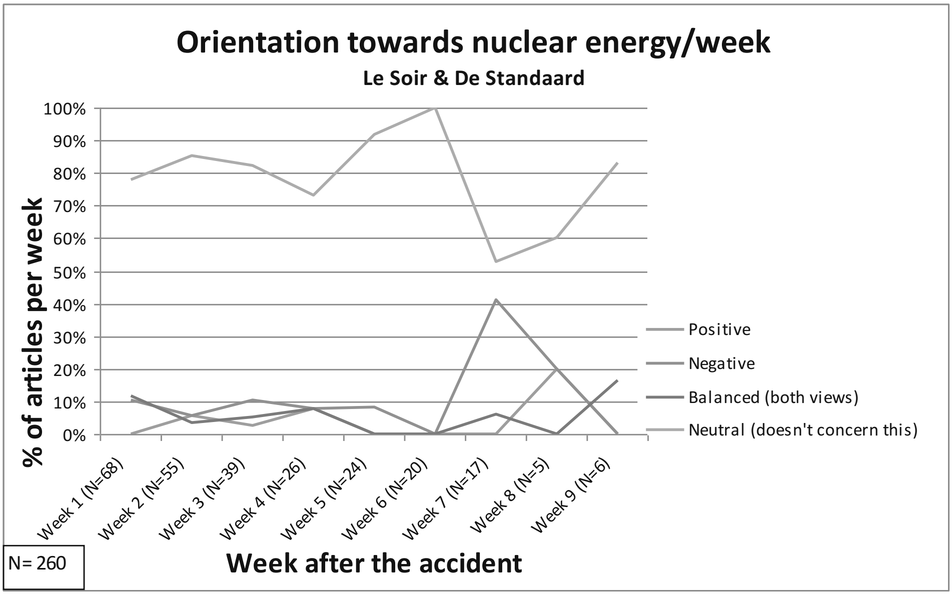

Figure 4: Orientation of the article towards nuclear energy per week

The comparison of the orientation of the articles towards nuclear energy in the weeks after the nuclear accident gives an indication that the negatively orientated articles in the week 7 are not only due to the accident in Fukushima. During the period of analysis, the world commemorated the 25th anniversary of the accident in Chernobyl (1986), still the worst nuclear accident in the history. In this period we observed a significant increase of articles negatively orientated towards nuclear energy and a significant decrease of neutral articles.

3.2. Public opinion after Fukushima nuclear accident

3.2.1. The relevance of the accident in Fukushima for Belgium

Even if the accident in Fukushima occurred far away from Belgium and was due to a combination of specific natural hazards, it was important to find out how was it perceived by the population in terms of its relevance and the feelings triggered by this accident.

Results show that public opinion in Belgium was divided as regards the relevance of the accident for Belgium (see Figure 5).

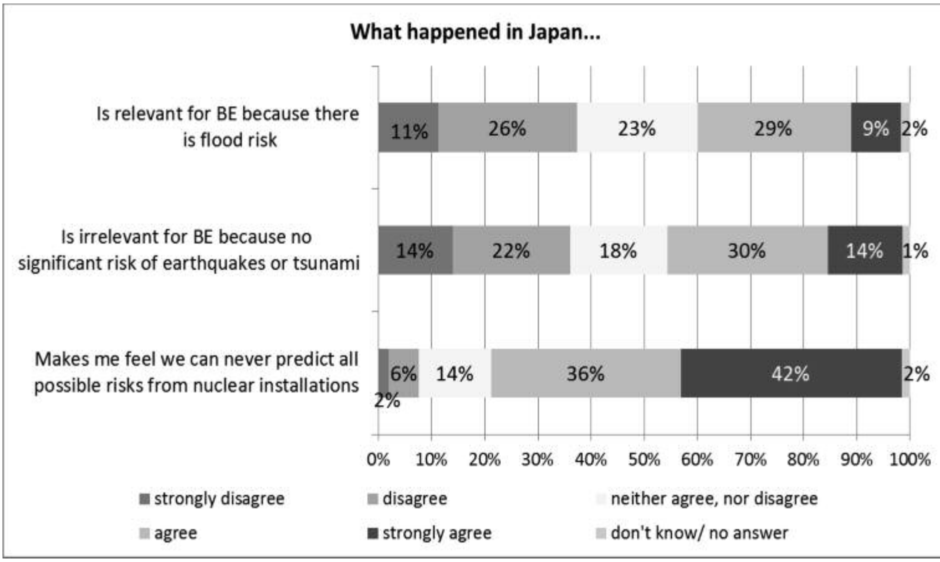

Figure 5: Opinions and feelings triggered by the accident at Fukushima (part 1), N=967

From the 967 respondents who had heard about the accident (out of 1020 interviewed), 38% thought that the accident in Japan is relevant for Belgium because there are flood risks, but almost the same percentage (37%) did not agree with this statement. 44% of the respondents (out of the 967) were of the opinion that the accident in Fukushima is not relevant for Belgium, since there are no significant risks of earthquakes or tsunami, while 36% disagreed with this. For the big majority (78% out of 967) the accident in Fukushima induced a feeling of uncertainty over how well we can predict the risks from nuclear installations.

As regards the management of nuclear installations in Belgium, 36% of the 967 respondents who had heard about the accident felt relieved that the nuclear installations in Belgium are well managed compared to 30% disagreeing this (Figure 7). What is somewhat striking is that 49% (out of 967) worry about dangers from Belgian nuclear installations, but only 31% want to know how to protect themselves in case of a nuclear emergency.

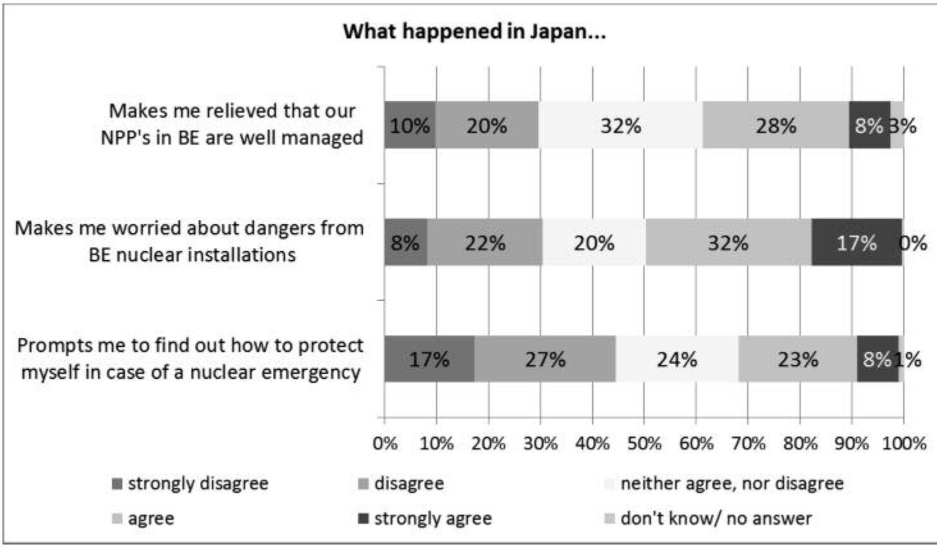

Figure 6 : Opinions and feelings triggered by the accident at Fukushima (part 2), N=967

3.2.2. Changes in the attitude towards nuclear

The attitude towards nuclear energy was first assessed through a number of general questions on which the respondents had to state their agreement or disagreement degree. The opinion on whether *"the reduction of the number of nuclear power plants in Europe is a good cause"* has been measured in all SCK•CEN Barometers since 2002 (see Figure 7). The percentage of respondents agreeing with this statement decreased from 66% in 2002 to 51% in 2006, and 47% in 2009. In 2011 the trend has changed: 61% of respondents agreed with this statement, which is comparable to the year 2002, before what is sometimes referred to as the "nuclear renaissance".

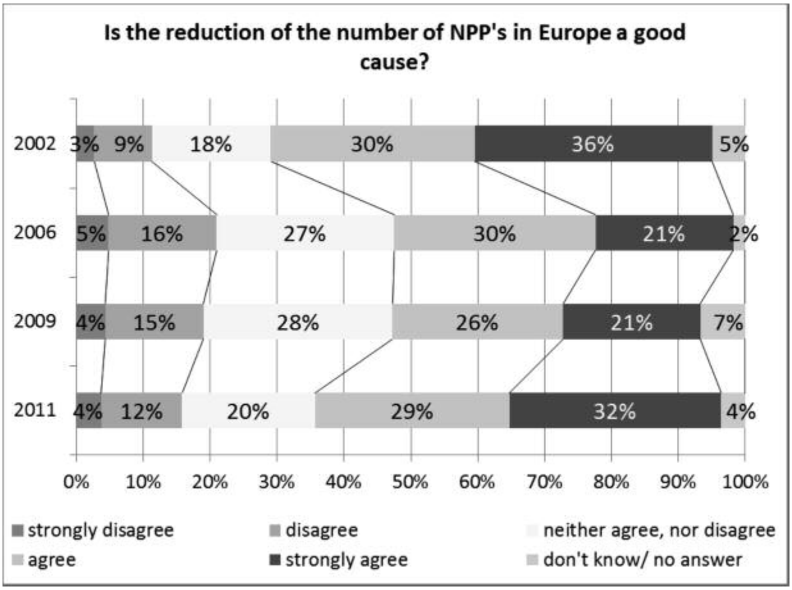

Figure 7 : On the reduction of NPP's in Europe, N=1020

The negative switch in the attitude towards nuclear energy was observed also with the statement *"in general, the benefits of nuclear energy outweigh the disadvantages"*. In 2011, 30% of the respondents agreed or strongly agreed with this statement, compared to 44% in 2009, and 39% disagreed in 2011, compared to 26% in 2009. This is illustrated in Figure 8.

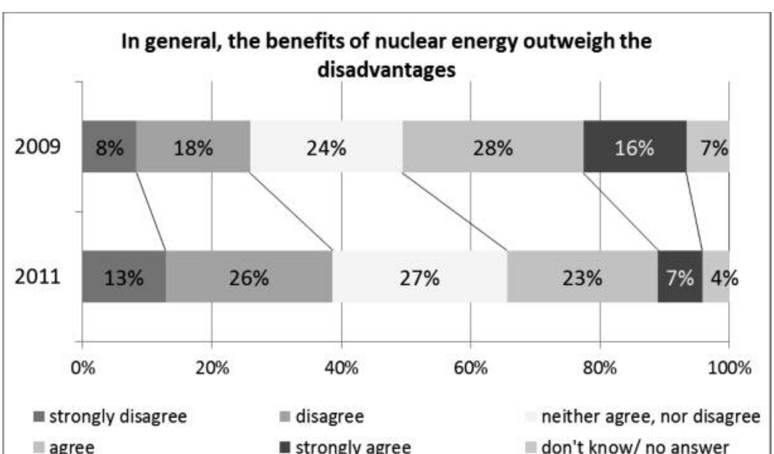

Figure 8 : On the benefits vs. disadvantages of nuclear energy, N=1020

Opinion about nuclear energy was afterwards measured by a direct question whether the respondent was in favour of nuclear energy or not. A change of attitude towards a more negative opinion about nuclear energy could be noticed in 2011 compared to 2009 (see Figure 9).

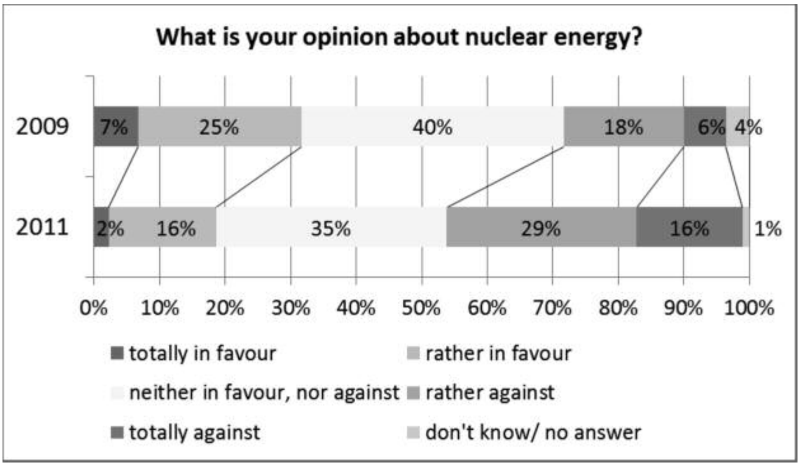

Figure 9 : Opinion about nuclear energy, N=1020

In 2009, the opinions about nuclear energy were rather balanced, with a slightly higher number of respondents in favour (32% pro, 24% against nuclear energy) and a large number of people undecided. In 2011, there is a clear switch: only 18% of the respondents are in favour of nuclear energy, whereas 45% are against. It can also be noticed that, similarly to 2009, more than one third of the population does not take a clear stand as regards nuclear energy.

4. Conclusions

The nuclear accident in Japan has predictably induced enormous media coverage. Mass media played a dominant role at all levels of communication on nuclear emergency issues. While they closely monitored the nuclear emergency management during the event phase, the media interest in the accident decreased rapidly with time in the weeks after the accident. Conflicts and disagreements were highly presented in the media articles.

Although the results of media analysis show that the overall orientation of the published articles towards nuclear energy was neutral, a clear emphasis on the negative aspects was observed in April 2011, at the time of the 25th anniversary of the Chernobyl accident.

Subsequent to the media reporting analysed in this study, changes in public opinion could be monitored in the third month after the accident; these changes point towards more negative opinions and attitudes with regards to nuclear energy as compared to previous years.

The relationship between the media content and the public opinion was thus confirmed.

4.1. References

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